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HENRY SALTONSTALL.[1]

IN his annual report, December 9, 1891, the President of the Institute of Technology made the following remark: "I long ago said that the greatest crisis through which a young institution of learning is called to pass, is, not with respect to its general scheme of work, not with respect to its finances, not with respect to its Faculty, but with respect to its Board of Trustees." What he then said on the subject of the cardinal importance of a right choice of trustees in an institution of learning, especially in its early days, he would now repeat with even more of emphasis, not only as the result of four years of added experience, but also out of his deep sense of the painful loss which the Institute of Technology has recently suffered in the death of one of its wisest, strongest, and bravest counselors.

Henry Saltonstall was born into one of the most distinguished families of Massachusetts, at Salem, the second of March, 1828. He fitted for college at Salem and at the Phillips Exeter Academy, entering Harvard in 1843; but by reason of ill health was obliged to give up his studies and go to sea. Returning after a year's absence, he reëntered college, becoming a member of the Class of 1848, in which he graduated seventh in scholarly rank, a Φ. B. K., and second marshal on class day.

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[1] Reprinted from *Technique* '97, 1896.

It is not needful to dwell at length upon Mr. Saltonstall's business career. It was from first to last marked by a masterly comprehension of affairs, by calm courage and decisive energy. He was for some years engaged in the East India trade, but when the outbreak of our Civil War made this line of business both unremunerative and hazardous he took up the work of textile manufacturing, to which he was to devote the remainder of his life. His first charge was the treasurership of the Chicopee Manufacturing Company, a small mill, which he ran to its fullest capacity throughout the war, often by night as well as by day, with a double staff of operatives. When he left this mill, in 1880, it had doubled its machinery, and its shares had advanced to five times their price in 1862. Meanwhile, in 1876, Mr. Saltonstall accepted the additional charge of the well-known Atlantic Mill at Lawrence, then lying idle and in a condition rapidly going from bad to worse. Within six months after Mr. Saltonstall became treasurer the mill was running with a full force, and in spite of unfavorable business conditions a substantial profit had been made. Mr. Saltonstall's success as manager of the two mills which have been named brought to him in 1880 an offer of the treasurership of the Pacific Mills in Lawrence, the largest and most important mills in this country, if not in the world. The story of Mr. Saltonstall's triumphant success in this great undertaking is common fame throughout Massachusetts and the whole textile manufacturing region of the United States. The condition of the mill was such as to require enormous expenditures — expenditures which, it might be said, were unprecedented in this department of business — for the renewal and reconstruction of the machinery; while the state of business in the woolen and worsted industry was such as to test to the utmost the courage and capacity of the new treasurer. No man ever rose more completely to the height of a situation. He restored the Pacific Mills to their former prestige, and won for himself a name among the very first of American captains of industry. To the close of his life he retained control of the affairs of this great corporation, having the fullest confidence of the stockholders and directors. Even while he was dying it was a source of inexpressible gratification to him that he was able, though with a faltering hand, to sign what he considered the most favorable report which, as treasurer, he had ever had occasion to render. The full story of Mr. Saltonstall's business career, in all its varied aspects and with greatest amplitude of detail, would be most instructive to the young men of the country; but our limits of space will not allow us to dwell longer upon it at this time.

Mr. Saltonstall was married in 1855 to Miss Georgiana Crowninshield, daughter of Hon. Nathaniel Silsbee, of Salem. An only child, a son named Gurdon, was born to them in 1856. In 1862 Mr. Saltonstall left Salem as a place of residence; and thereafter during the winters occupied his house on Commonwealth Avenue, Boston, one of the first houses built in that district, spending his summers on his beautiful estate in Lynnfield, on the shore of Suntaug Lake. To the inexpressible affliction of his parents, the son died in his twenty-second year. Early in his college career he had attempted a difficult canoe voyage, in which he had endured hardships and exposures which had brought on a fatal disease. After a long struggle for life, this only child of devoted parents died in the south of France in 1878.

But it is Mr. Saltonstall's relations to this school that the historian of *Technique* has chiefly to relate. Mr. Saltonstall was elected to the Corporation of the Institute of Technology in 1885, and in May, 1887, became a member of the Executive Committee. From that time onward, until near his decease, he performed a part in the support and development of this school of industrial science which it would be impossible to overstate. His knowledge of business, his mastery of affairs, would alone have made him a useful member of the Committee; but his splendid enthusiasm, his magnificent moral courage, his buoyant temper, which rose ever higher at the sight of obstacles and dangers, his uncompromising regard for justice, his sense of humor, his spirit of fun, all came in to make up that totality of faculties and qualities which rendered Henry Saltonstall an invaluable counselor. No words will enable one who has not been intimately associated with Mr. Saltonstall to understand the uplifting influence of his presence, his words, and his example.

Mr. Saltonstall's years of service as a member of the Executive Committee of the Massachusetts Institute of Technology have become a part, not only of the history, but of the present life of the school. To separate what he did and what he was from what the Institute today is, would be as impossible as for Shylock to take his pound of flesh nearest to the heart without spilling the blood. He saw the school increase from six hundred students to twelve hundred. He saw building after building rise to make the new Institute. He rejoiced in it all. Of it all he was a part. As those years went on, his affection for and devotion to the school, which he had helped to guide through so many difficulties and helped to guard against so many dangers, grew stronger. He frequently spoke of the Institute of Technology as among his dearest interests in life; and it was with the deepest reluctance that in June, 1894, the progress of disease compelled him to relinquish his membership in the Executive Committee, though still remaining in the Corporation. On the third of December, in the same year, Mr. Saltonstall died at his Boston home, having for months borne great suffering with undaunted courage and fortitude.

AN APPARATUS FOR ILLUSTRATING PHASE-DIFFERENCES.

BY LOUIS DERR, M.A.

Read February 13, 1896.

WHEN an harmonic electromotive force is applied to a circuit of ohmic resistance R, inductance L, and capacity C, there exists in general a phase-difference θ between the electromotive force and the resulting current, whose magnitude is expressed by the equation

$$\tan\theta = \frac{Lp}{R} - \frac{1}{CRp},$$

in which p is a quantity equal to 2π times the number of alternations of the current per second. From this equation it appears that θ may be positive, negative, or zero, according to the relative magnitude of the two terms. If the circuit consists of an impedance coil, the second term is negligible, θ is positive, and the current is behind the electromotive force in phase; if the circuit contains a condenser only, the second term predominates, θ is negative, and the current is ahead of the electromotive force.

To show these and other phase-relations on a scale suited to lecture-room illustration, the apparatus here described has been devised by the writer, its operation depending on the principle that when an electric current is sent through a wire lying perpendicularly across a magnetic field a force is developed which urges the wire at right angles to both the direction of the field and the current. A powerful electromagnet is mounted on an upright stone base, and a wire is stretched across the field between its poles. At the top of the apparatus the wire terminates in the free end of a light metallic hinge, to which a small mirror is cemented. The to-and-fro vibrations of the wire may be observed by a beam of light reflected from the mirror to a screen, the hinge preventing all lateral motion and twisting. The other end of the wire carries a tuning-pin and a device providing a slight angular motion of the whole wire for adjusting the mirror.

An alternating current sent through the wire urges it alternately backward and forward, and if the tuning-pin is turned until the period of free vibration of the wire coincides with that of the current the wire springs into vigorous and distinctly audible vibration, and the spot of light reflected from the mirror on the screen elongates into a vertical line. That this line is traced by the moving spot is easily shown by putting in the path of the reflected beam a mirror revolving about a vertical axis, and thence reflecting to the screen. On turning the second mirror the successive positions of the spot fall in different verticals, and the result on the screen is a very perfect sine-curve, a faithful representation of the vibrations of the wire. Figure 1 shows the arrangement of mirrors, using two wires.

With two such wires the observation of the phase-difference between two currents is easily made. With everything at rest, the mirrors are adjusted until the spots of light reflected on the screen are coincident. If now the wires are connected into separate circuits carrying currents, the lines of light on the screen remain superposed, the one corresponding to the stronger current appearing slightly longer than the other. On turning the revolving mirror any phase-difference between the currents is at once shown by the horizontal displacement of the lagging curve past the other, exactly as text-book diagrams of such curves are drawn.

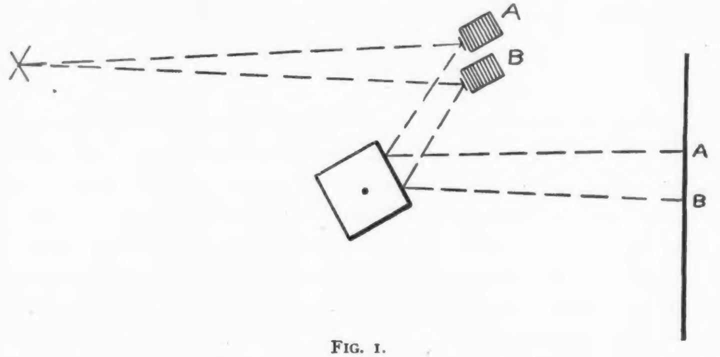

FIG. 1.

To observe phase-differences between voltage and current under various conditions, one wire is connected to the terminals of the given circuit through a suitable non-inductive resistance. The resulting current will then be sensibly in phase with the applied electromotive force, and the curve on the screen may be taken as representing the changes of the electromotive force itself. The other wire, shunted if necessary, carries the current to be studied. One of the curves on the screen may be colored and thus identified by putting a slip of

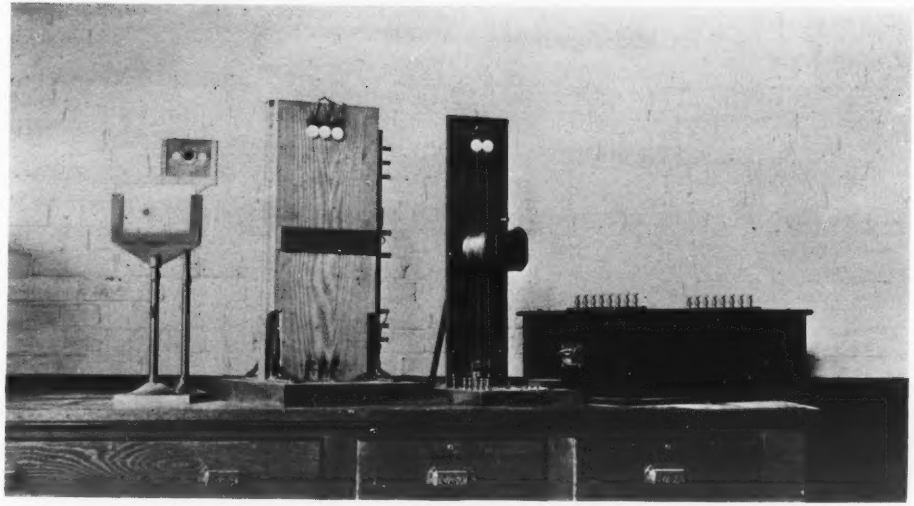

Fig. 3.

colored glass in front of the corresponding mirror. The phase-relations between voltage and current in circuits of different character may be conveniently compared by using a three-point switch and connections as shown in Figure 2, where L represents an impedance coil, R a non-inductive resistance, and C a condenser. The circuits can thus be interchanged as rapidly as desired; and the instant shifting of the curves on the screen, corresponding to the character of the circuit employed and agreeing with the conclusions of a preceding paragraph, is quite striking. With the apparatus here shown a current of one ampere in the wire and a total length of about thirty feet in the reflected beam give curves on the screen of two feet amplitude.

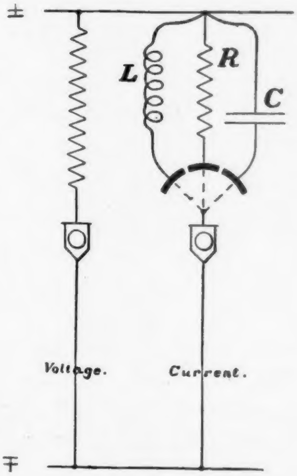

FIG. 2.

The angular relations between the currents in a polyphase circuit may be shown to an audience if the necessary number of mirrors is employed; the reactions of condenser and impedance coil upon each other in a circuit adjusted for resonance may be illustrated if a high-voltage condenser of large capacity is available; and the phase-relations between the primary and secondary voltage and current of a transformer may be demonstrated. Figure 3 shows two-wire and three-wire apparatus, together with the 17-microfarad condenser and color-screens used in the experiments. A foot rule is also photographed to show the size of the instruments. Exact dimensions are not given, as the size of every part may be varied within wide limits.

It should be stated that the results given by the apparatus in its present form are not quantitatively accurate within several per cent., especially if the currents in the wires are not truly sinusoidal.[1] The discrepancies between calculated phase-differences and those observed with the apparatus, while unfitting it for precise measurement, do not, however, interfere with its usefulness as an instrument for purposes of illustration.

ROGERS LABORATORY OF PHYSICS.
September, 1896.

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[1] Thesis of Messrs. Fish and Libby, 1895.

ON THE HYDROLYSIS OF FERRIC CHLORIDE.

By H. M. GOODWIN, Ph.D.

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INTRODUCTION.

THE following article contains the results of some experiments made during the summer of 1895 on the changes which take place in a neutral ferric chloride solution when suddenly diluted. I was led to this investigation during the course of some experiments on its electrical conductivity. It was observed that, when a series of measurements of the conductivity were made in the usual way in an Arrhenius cell, at a dilution of about a thousand liters ($v = 1,000$) a constant setting on the bridge could no longer be obtained. The conductivity slowly, but unmistakably, increased with the time, while at the next dilution ($v = 2,000$) this increase became very rapid. I find this phenomenon has also been observed and described in a note by Foussereau.[1] I also observed that the solution, which when first diluted was practically colorless, rapidly turned reddish yellow, deepening to a reddish brown.[2] This color reaction was no less marked than that accompanying the change in conductivity. Indeed, when 1 cc. of a 0.1-normal solution is diluted to a liter, one might hope, with a good colorimeter, to follow it colorimetrically. A 0.0001-normal solution, which was practically colorless on first dilution, became within half an hour much deeper in color than a 0.01-normal solution which had stood for days. That the changes in color and conductivity are allied phenomena was evident, and the reaction seemed so interesting that I determined to study it further. In the following experiments the velocity of the reaction taking place on diluting

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[1] Foussereau, C. R., **103**, 42 (1886).

[2] Since the greater portion of this paper was written an article has come to my notice in the Gazetta Chimica Italiana, **23**, 1 (1895), by Antony and Giglio, in which the color phenomena of dilute neutral ferric chloride solutions are studied.

a solution of ferric chloride with varying amounts of water is followed by measuring the conductivity of the solution at different times. The reaction which probably takes place will be considered later in the light of the experimental results which were obtained.

EXPERIMENTAL RESULTS.

All measurements were made in a large thermostat maintained at a constant temperature of 25° C. The variations of temperature during a run of several days' duration were not greater than 0.2°–0.3°. When a discontinuous run was made, and the temperature allowed to fall, the results are so indicated. The conductivity was measured by the usual Kohlrausch method. For the more concentrated solutions, in which the reaction could be followed at leisure, the solutions were made up and kept in glass-stoppered bottles which had previously been thoroughly steamed to dissolve out as much soluble matter in the glass as possible. When a measurement was to be made a portion was poured into the conductivity cell of the Arrhenius form. This procedure was impossible for very dilute solutions, in which the velocity of the reaction was great at the start. For this purpose I used 500 cc. wide-necked bottles, which had been previously steamed, as measuring cells; the electrodes were firmly fixed in a piece of vulcanite, which was held in position by a large rubber stopper. The capacity of this cell was determined under exactly the same conditions as regards position of electrodes, quantity of solution, etc., as in the measurements themselves. If it was desired to dilute a solution five hundred times, 499 grams of pure water were weighed out in the bottle, placed in the thermostat, and allowed to assume the constant temperature as indicated by a constant conductivity. 1 cc. of the solution, also at 25°, was then run in, at a noted time, by a carefully calibrated pipette, the bottle closed with a ground-glass stopper and vigorously shaken, the electrodes instantly replaced, and a measurement taken as quickly as possible. The operation of diluting, shaking, and making a measurement took from three quarters of a minute to a minute. The temperature of so large a mass of liquid did not appreciably change during the few instants' shaking, so that with rapid work a reliable initial measurement could be obtained within a minute after the dilution. The frequency of the readings following depends on the velocity of the reaction and the minuteness with which it is desired to follow it. For convenience, the conductivity method, when applicable, is unsurpassed for following the course of a reaction, as no further manipulation is necessary than reading the position of the minimum from time to time.

For the neutral ferric chloride solution with which the following experiments were made I am indebted to Dr. A. A. Noyes, the solution being a part of that used by him in his investigation on the "Velocity of the Reaction Between Ferric Chloride and Stannous Chloride."[1] Analysis showed the solution to be neutral and 0.303 molecular normal. It had stood over six months when analyzed, and was of a deep yellowish-red color. In what follows, the concentration of all solutions is expressed in gram molecules per liter unless otherwise stated, and the word normal is to be understood in that sense.

I give, in the first place (Table I), the results of a duplicate series of measurements of ferric chloride for concentrations from 0.101- to 0.00158-normal, the dilutions being made in the usual manner in an Arrhenius cell. The conductivity is expressed in mercury units. Nothing abnormal was noticed in these measurements, the conductivity reaching a constant value when the temperature became constant within a few minutes after each dilution. The color of the solution became fainter and fainter with each successive dilution. On attempting to make the next and all following dilutions the phenomenon already described first made itself evident.

TABLE I.

Conductivity of $FeCl_3$ at 25° C.

Dilution. v.	Concentration. $c = \frac{1}{v}$.	Molecular conductivity.	Mean.	Equivalent conductivity.
9.90	0.1010	244.3 244 5	244.4	81.5
19.80	0.0505	290.0 290.3	290.2	96.7
39.6	0.02525	339.0 338.8	338.9	113.0
79.2	0.01263	390.5 391.1	390.8	130.3
158.4	0.006315	445.2 444.6	444.9	148.3
316.8	0.003158	498.5 499.3	498.9	166.3
634.0	0.001579	545.0 545.6	545.3	181.8

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[1] Noyes, Zeitschrift für physikalische Chemie, **16**, 546 (1895).

Tables II to VII, inclusive, contain the results of measurements of the increase of the electrical conductivity with the time, for solutions varying in concentration from 0.002422- to 0.000101-normal. For solutions stronger than 0.0012-normal it was found advantageous to make the dilutions in bottles and to transfer a portion to the conductivity cell when a measurement was desired. As will be seen from the figures, the reaction did not begin with these solutions until after the elapse of a considerable time, so that the reaction could be followed at leisure. For very dilute solutions the dilution and measurements were made in the large bottles already described. It was found impossible to get reliable initial values for dilutions greater than about 0.0001-normal, as in such solutions the initial velocity of the reaction became enormous.

TABLE II.

Conductivity of $FeCl_3$, 0.002422-normal at 25°. (2 cc. of 0.303-normal diluted to 250 cc.)

Time.		Molecular conductivity.	Equivalent conductivity.	Remarks.
	h. m.			
May 24	11 45	.....	.....	Diluted.
“ “	11 46	519.0	173.0	Solution slightly yellow.
“ “	12 0	519.0	173.0	
“ “	12 15	519.6	173.2	
“ “	12 30	521.4	173.8	
“ “	1 15	529.8	176.6	
“ “	1 45	544.2	181.4	Color began to deepen.
“ “	2 15	561.9	187.3	
“ “	2 45	582.9	194.3	
“ “	3 15	603.0	201.0	
“ “	3 45	621.3	207.1	
“ “	4 15	639.9	213.3	
“ “	4 45	652.5	217.5	
“ 25	12 0	787.2	262.4	
“ 29	4 0	894.3	298.1	Temperature fell to room temperature.

TABLE III.

Conductivity of $FeCl_3$, 0.001211-normal at 25°. (1 cc. of 0.303-normal diluted to 250 cc.)

Time.			Molecular conductivity.	Equivalent conductivity.	Remarks.
	h.	m.			
May 23	4	0	.....	.....	Diluted.
" "	4	1	556.5	185.5	Solution nearly colorless.
" "	4	5	556.5	185.5	
" "	4	10	555.9	185.3	
" "	4	15	557.4	185.8	
" "	4	20	558.0	186.0	
" "	4	30	563.7	187.9	
" "	4	45	577.5	192.5	Color begins to increase.
" "	5	0	596.1	198.7	
" "	5	30	649.5	216.5	
" "	6	0	690.0	230.0	
" "	6	30	722.1	240.7	
" "	7	0	747.9	249.3	
" "	7	30	768.0	256.0	
" "	8	0	784.8	261.6	
" "	9	0	811.5	270.5	
" "	10	0	835.8	278.6	
" 24	5	0	901.8	300.6	Very deeply colored.
" 25	5	0	928.2	309.4	Temperature was kept at 25° only during measurements from here on.
" 29	4	0	1,011.0	337.0	
June 3	5	0	1,053.0	351.1	
" 12	3	0	1,070.0	356.6	
" 20	3	0	1,080.0	360.0	

TABLE IV.

Conductivity of $FeCl_3$, 0.000802-normal at 25°. (1 cc. of 0.303-normal diluted to 375 cc.)

Time.				Molecular conductivity.	Equivalent conductivity.	Remarks.
	h.	m.	s.			
May 30	12	0		.....	.....	Diluted.
" "	12	1	30	579.6	193.2	Solution practically colorless.
" "	12	3		579.6	193.2	
" "	12	4		579.3	193.1	
" "	12	5		580.5	193.5	
" "	12	6		581.7	193.9	
" "	12	15		589.8	196.6	
" "	12	30		633.0	211.0	Color begins to deepen.
" "	12	45		681.9	227.3	
" "	1	5		732.0	244.0	
" "	1	30		780.0	260.0	
" "	2	0		821.4	273.8	
" "	3	0		874.5	291.5	
" "	4	0		905.0	301.8	
" "	5	0		919.0	306.3	
June 1	5	30		1,009.0	336.2	Deep reddish yellow.
" 3	4	0		1,051.0	350.3	
" 12	2	15		1,103.0	367.7	
" 20	1	15		1,108.0	369.2	

TABLE V.

Conductivity of $FeCl_3$, 0.000606-normal at 25°. (1 cc. of 0.303-normal diluted to 500 cc.)

Time.	h.	m.	Molecular conductivity.	Equivalent conductivity.	Remarks.
May 30	11	30	.....	.....	Diluted.
“ “	11	31	591.6	197.2	Solution colorless.
“ “	11	32	591.6	197.2	
“ “	11	33	592.2	197.4	
“ “	11	34	592.8	197.6	
“ “	11	35	594.0	198.0	
“ “	11	39	599.2	199.8	
“ “	11	45	619.5	206.5	Begins to turn yellow.
“ “	11	50	639.0	213.0	
“ “	11	55	666.9	222.3	
“ “	12	12	738.0	246.0	
“ “	12	40	780.0	260.0	
“ “	1	0	854.0	284.7	
“ “	1	40	905.0	301.6	
“ “	2	35	942.0	313.9	
“ “	3	40	979.0	326.3	Deeply colored.
“ “	4	37	998.0	332.5	
June 1	5	0	1,061.0	353.6	
“ 3	4	15	1,090.0	363.4	
“ 12	2	0	1,132.0	377.3	
“ 20	1	30	1,137.0	379.0	

TABLE VI.

Conductivity of $FeCl_3$, 0.000303-normal at 25°. (5 cc. of 0.03-normal diluted to 500 cc.)

Time.	h.	m.	Molecular conductivity.	Equivalent conductivity.	Remarks.
July 4	12	35	.....	.....	Diluted.
“ “	12	36	601.5	200.5	Solution colorless. Begins to turn yellow immediately.
“ “	12	37	635.7	211.9	
“ “	12	39	712.8	237.6	
“ “	12	40	735.6	245.2	
“ “	12	45	813.0	271.0	
“ “	12	50	860.0	286.6	
“ “	12	55	893.0	297.7	
“ “	1	0	915.0	305.0	
“ “	1	10	951.0	317.0	
“ “	1	20	977.0	325.7	
“ “	1	50	1,019.0	339.7	
“ “	2	50	1,054.0	351.3	
“ “	3	36	1,070.0	356.7	
“ “	4	36	1,081.0	360.3	
“ “	5	5	1,085.0	361.7	
“ 5	2	0	1,107.0	369.0	
“ 6	1	0	1,118.0	372.7	

TABLE VII.

Conductivity of $FeCl_3$, 0.000101-normal at 25°. (1 cc. of 0.0303-normal diluted to 300 cc.)

Time.				Molecular conductivity.	Equivalent conductivity.	Remarks.
	h.	m.	s.			
July 4	1	30		...	...	Diluted.
“ “	1	31	10	759	253	Solution colorless.
“ “	1	31	45	819	273	
“ “	1	32		837	279	
“ “	1	33		885	295	Solution became perceptibly yellow.
“ “	1	34		924	308	
“ “	1	35		948	316	
“ “	1	37		981	327	
“ “	1	40		1,008	336	
“ “	1	45		1,038	346	
“ “	2	0		1,074	358	
“ “	2	30		1,095	365	
“ “	4	0		1,101	367	
“ “	4	30		1,107	369	
“ “	5	15		1,107	369	Solution reddish yellow.
“ 5	2	15		1,110	370	
“ 6	1	10		1,107	369	

The course of the reaction which here takes place and its dependence on the dilution is best seen from the curves (Figure 1) representing the results given in Tables II to VI.

Here the molecular conductivity is plotted as ordinates and the corresponding times as abscissæ. A consideration of the curves shows that:

First. The molecular conductivity of dilute solutions increases with the time.

Second. The rate of increase increases very rapidly with the dilution. These conclusions agree with Foussereau's statement, but as he gives no data a numerical comparison cannot be made.

Third. The increase in the conductivity does not begin at once on dilution, but only after the lapse of a certain time.

Fourth. The time required to start the reaction increases very rapidly with the concentration. Thus the reaction, as indicated both by increase in conductivity and change of color, begins only after the lapse of 1 minute for a 0.0006-normal solution, 15 minutes for a 0.0012-normal solution, 45 minutes for a 0.0024-normal solution.

Fifth. The time required for the solution to reach a state of equilibrium increases enormously with the concentration. Thus a 0.0001-normal solution (Table VII) requires but three hours, while a 0.0006-normal solution (Table V) requires over a week.

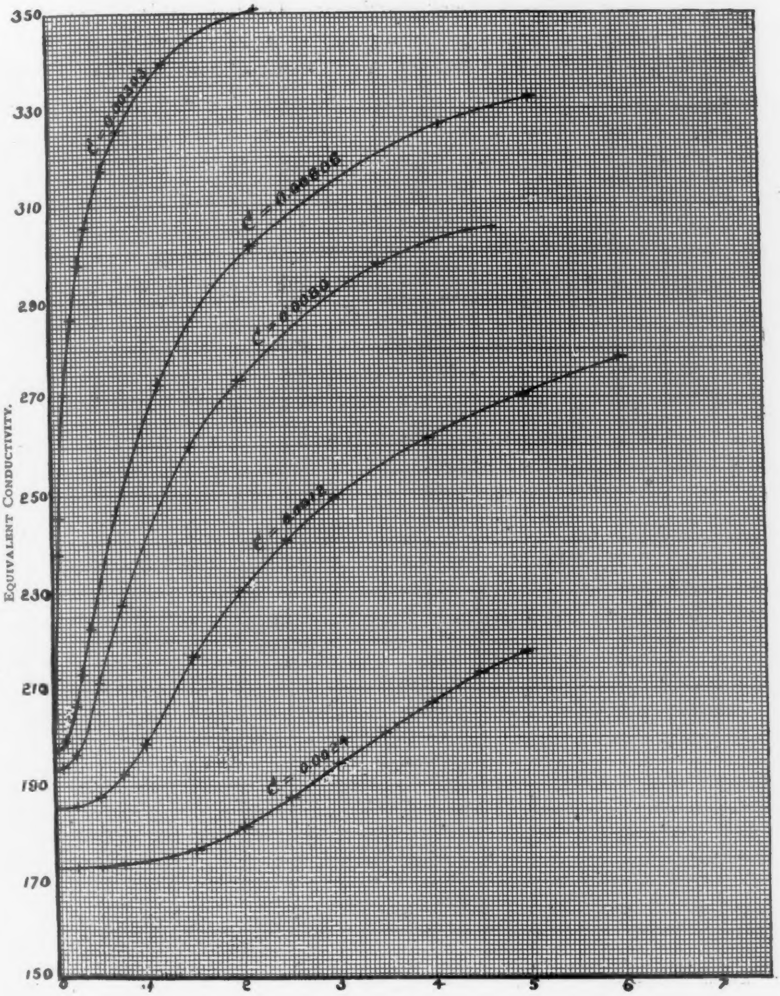

FIG. 1.

Sixth. The reaction when once started progresses slowly at first, then more and more rapidly up to a certain point where a maximum rate is reached, and then more and more slowly, until finally it ceases.

The remarkable inertia of the reaction and its great dependence on the concentration is more strikingly shown in Table VIII, which contains measurements of still more concentrated solutions. Here it will be seen that as the concentration increases the solution remains clear and only slightly colored, and its conductivity is constant for days before any change is noticed. And here, too, another phenomenon not previously observed with dilute solutions manifests itself. The change in conductivity and color is accompanied by a turbidity of the solution, which gradually increases in the more concentrated solutions to a heavy, yellowish precipitate. I thought at first that this might be due to the action of soluble matter in the glass bottles in which the solutions were kept. I accordingly repeated the experiments, using flasks of thoroughly steamed, hard Jena glass, but with the same results. The formation of the precipitate, which is probably the oxychloride, is therefore independent of the vessel in which the solution is kept. Owing to the formation of this precipitate and resulting uncertain change in concentration of the solution, it was thought useless to follow the changes in these solutions until they reached a state of equilibrium. Only in very dilute solutions — less than 0.0025- to 0.003-normal — can this be done with any degree of certainty.

The *initial* values given in Table VIII are, however, reliable measurements of the conductivity at the respective dilutions, and fall almost exactly on the curve representing the initial values given in Tables I to VI.

TABLE VIII.

Molecular Conductivity of $FeCl_3$ at 25°.

Concentration.	$t = 0$.	$t = 1$ day.	$t = 2$ days.	$t = 3$ days.	$t = 4$ days.	$t = 14$ days.
0.0303	327.6 Clear.	327.6 Clear.	327.0 Clear.	327.9 Clear.	328 2 Clear.	390.0 Very turbid.
0.01515	377.7 Clear.	376.2 Clear.	377.1 Clear.	377.1 Clear.	392.4 Slightly turbid.	..... Very turbid.
0.00758	432.3 Clear.	432. 3 Clear.	504.9 Very turbid.	532.5 Very turbid.	563.4 Very turbid.	....
0.00379	485.4 Clear.	636.0 Slightly turbid.	708.0 Turbid.	729.0 Turbid.	....	....
0.00189	534.3 Clear.	810.0 Clear.	855.0 Clear.	882.0 Clear.	..... Clear.	..... Clear.

EXPLANATION OF RESULTS.

The following explanation of these results, which is the most plausible which has suggested itself, is the outcome of the discussion of the preceding data with my friend, Dr. A. A. Noyes, whose valuable suggestions it is a pleasure to acknowledge here.

Ferric chloride is, as is well known, more or less hydrolyzed in aqueous solution, the amount of hydrolysis depending on the dilution. When a concentrated solution in which the hydrolysis is small is suddenly diluted, instantly and simultaneously with the increase in electrolytic dissociation further hydrolytic dissociation takes place, the ferric ions uniting with the hydroxyl ions of the water. It will be seen later, however, that there is good reason to believe that this hydrolysis does not result in the formation of electrically neutral ferric hydrate (FeO_3H_3), which is probably a strongly dissociated base, but in the formation of the bivalent ion FeOH resulting from its dissociation. That is to say, the *a priori* not improbable assumption is here made that, as in the case of polybasic acids the successive

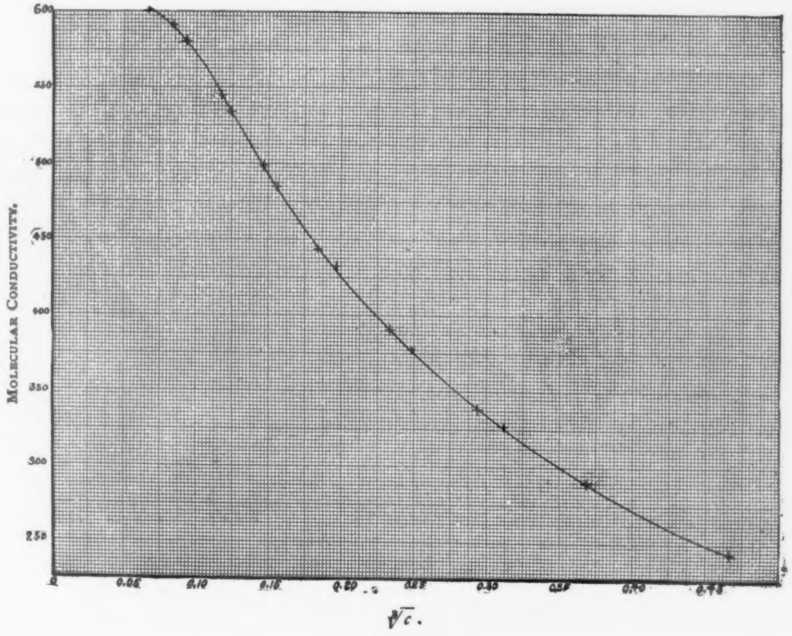

FIG. 2.

hydrogen ions dissociate less and less readily, so in the case of this polyacidic base the first and also the second hydroxyl ion splits off in dilute solution nearly completely, and it is only the bivalent basic ion FeOH which is slightly enough dissociated to give rise to hydrolysis. As already stated, an *a posteriori* justification of this assumption is furnished by the experiments themselves.

The result on first diluting the solution is, therefore, that the hydrolytic reaction $\overset{+++}{\mathrm{Fe}} + \mathrm{H_2O} = \overset{+\,+}{\mathrm{FeOH}} + \overset{+}{\mathrm{H}}$ takes place, and the conductivity of the solution is thereby increased by an amount proportional to the difference of the velocity of migration of the hydrogen and ferric ions. Consequently the initial electrical conductivity must increase more rapidly than can be accounted for by increasing electrolytic dissociation alone. That this is the case is seen by reference to Figure 2, in which the initial values of the equivalent conductivity are plotted as ordinates and the cube root of the concentrations ($\sqrt[3]{c}$) as abscissæ. If we further assume that the $\overset{+\,+}{\mathrm{FeOH}}$-ions are colorless, or nearly so, then on first diluting a solution the color will simply become fainter and fainter in proportion to the decrease in concentration.

To explain now the further increase of conductivity with the time and the attendant change in color of the solution, we have only to assume that the deeply colored colloidal ferric hydrate described by Graham[1] is gradually formed according to the reaction

$$x\mathrm{Fe(OH)_3} = (\mathrm{FeO_3H_3})_x,$$

or what amounts to the same thing:

$$x\overset{+\,+}{\mathrm{FeOH}} + x2\overset{-}{\mathrm{OH}} = (\mathrm{FeO_3H_3})_x.$$

It is assumed, for simplicity, that the colloidal hydrate is a polymer of the theoretical formula, although the experiments of Maguier de la Source[2] and Sabanejeff[3] indicate that the probable composition is $\mathrm{FeCl_3}x(\mathrm{FeO_3H_3})$, x being very large, however, compared to unity. This reaction is, for the dilutions investigated, practically non-reversible. Krecke[4] found that for solutions less than 1 per cent. this was the case.

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[1] Graham, Liebig's Annalen, 121, 46.

[2] C. R., 90, 1352.

[3] Sabanejeff, Chemisches Centralblatt, 1, 11 (1891).

[4] Krecke, Jour. pract. Chem. (2), 3, 286.

Since the equilibrium of the true hydrolytic reaction is determined by the concentration of the $Fe(OH)_3$ molecules or of the $\overset{+}{\text{Fe}}\overset{+}{\text{O}}\text{H}$-ions, and not of the polymerized molecules, as fast as the former is diminished by the colloidal reaction further hydrolytic dissociation must take place, and hence the conductivity must increase. Moreover, since the velocity of the colloidal reaction depends primarily on the amount of hydrolyzed salt, it too must increase with the dilution, as was also found to be the case.

The remarkable initial lag in the reaction is most probably due to the fact that the reaction product itself, the colloidal hydrate, accelerates the reaction in the same way, perhaps, that the velocity of crystallization from supersaturated solutions increases as the number of crystal centers themselves increase. Consequently the velocity becomes at first greater and greater as the reaction progresses, owing to the increase in the amount of colloidal ferric hydrate present, but later reaches a maximum, and finally decreases, owing to the diminution in concentration of the substance undergoing the reaction (the FeO_3H_3 or FeOH).

The fact that the reaction takes place so much more rapidly in dilute solutions is due to the much larger proportion of FeOH or FeO_3H_3 which these contain. The speed in dilute solutions is, moreover, also greatly increased by reason of the fact that the greater amount of colloidal ferric hydrate produced from the cause just mentioned, itself enormously accelerates the reaction; for the acceleration of this reaction by any cause is itself a secondary cause of a further acceleration.

Calculation of the Hydrolytic Dissociation.

If the preceding explanation of the time increase of the conductivity of dilute solutions of ferric chloride is true, it is clear that we must distinguish between the initial and final value of the hydrolysis in computing its value. Reasoning from the results obtained, it would seem probable that with concentrated solutions the colloidal reaction would practically begin only after an infinite time. To test this conclusion, I made up and measured a fresh solution of neutral ferric chloride, as follows: An approximately 0.03-normal solution, made up by dissolving 2.5660 grams of especially sublimed ferric chloride in 500 cc. of water. The solution was of a clear light-yellow color.

Subsequent analysis showed the solution was 0.03101-normal with respect to iron, and 0.03084-normal with respect to chlorine. It was assumed neutral and equal to 0.0309-normal.

The conductivity of this solution and of a portion diluted ten times was measured within ten minutes after making up. The values obtained were $\mu = 324.0$ and $\mu = 499.5$, respectively, whereas the values interpolated from Figure 2 for the same concentrations were $\mu = 323$ and $\mu = 498$. The agreement is complete. It is proved, therefore, that there was no appreciable amount of colloidal hydrate in the original 0.3-normal solution with which the preceding experiments were made, although it had stood over a year, and that the values given in Table I truly represent the initial conductivity at the given dilutions.

Let us now suppose that at a given dilution one molecule of ferric chloride is α per cent. electrolytically dissociated according to the reaction

$$\text{FeCl}_3 \rightleftarrows \text{Fe} + 3\text{Cl},$$

and β per cent. hydrolytically dissociated according to the reaction

$$\text{FeCl}_3 + \text{H}_2\text{O} = \overset{+}{\text{Fe}}\overset{+}{\text{O}}\text{H} + \overset{+}{\text{H}} + 3\overset{-}{\text{Cl}}.$$

The solution will therefore contain $1 - \alpha - \beta$ molecules of undissociated ferric chloride, α ferric ions, and β FeOH-ions. A knowledge of α and β will, therefore, completely determine the nature of the solution. Of the molecular complexes present, only the ions contribute to the conductivity of the solution. If u, u', u'', and v are the velocities of migration of the ferric, hydrogen, $\overset{+}{\text{Fe}}\overset{+}{\text{O}}\text{H}$, and chlorine ions, respectively, then the equivalent conductivity of the solution is given by

$$\mu = \alpha(u + v) + \beta\left(\frac{2u'' + u' + 3v}{3}\right). \qquad 1)$$

On the other hand, the total number of molecular complexes i will determine the lowering of the freezing point of the solution; *i.e.*,

$$\begin{aligned} i &= 1 - \alpha - \beta + 4\alpha + 5\beta. \\ &= 1 + 3\alpha + 4\beta. \end{aligned} \qquad (2)$$

We have here two independent equations for determining α and β, provided μ and i are measured and the remaining quantities in (1) are known. Of these, the velocities of migration of the ferric and of the FeOH-ions have not been determined. We may, however, by analogy, and with the help of the principle that the rates of migration of all such ions are of the same order of magnitude, estimate their values with sufficient accuracy. We will assume them equal to each other, and that the numerical value at 25° is 50.[1] Taking Ostwald's values of 70 and 325 for chlorine and hydrogen, respectively, (1) may be written

$$\mu = 120\alpha + 212\beta, \qquad (1a)$$

and

$$\alpha = \frac{i-1}{3} - \frac{4}{3}\beta. \qquad (3)$$

Hence, solving for β:

$$\beta = 2.31\left(\frac{\mu}{120} - \frac{i-1}{3}\right). \qquad (4)$$

α and β can be computed by this method only for those concentrations at which both freezing point and conductivity measurements are possible. It will be seen, however, from the following table that the values of α and β computed in this way give for the total dissociation of the salt, *i. e.*, $\gamma = \alpha + \beta$, very nearly the same values as found for barium chloride, a typical binary salt. I have therefore calculated β for the dilute solutions where reliable freezing-point data are not obtainable, on the assumption that the amount of undissociated ferric chloride present at each dilution is the same as the amount of undissociated salt in the case of the bivalent chlorides. Substituting $\alpha = \gamma - \beta$ in (1*a*), we get $\mu = 120\gamma + 92\beta$, or $\beta = \frac{\mu - 120\gamma}{92}$, from which β is calculable at once by giving γ the values of $\frac{\mu}{\mu_\infty}$ for barium chloride.

For measurements of the lowering of the freezing point I have to thank the kindness of my friend, Dr. Harry C. Jones, who measured several solutions, made up from my stock solution, by his well-known method.[2] His results are given in Table IX.

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[1] The mean of the velocities of migration of copper, zinc, and magnesium ions are about two units greater than that of sodium from Kohlrausch's values of μ_∞ for these sulphates of these metals; and as, so far as the meager measurements on ferrous chloride and sulphate show, the ferrous ion (and, presumably, also the ferric ion) moves even slower than the above-mentioned bivalent ions, we may assume as a probable upper limit for velocity of migration of the ferric ion a value a little greater than that of sodium. The latter at 25° is 49, hence the approximate value 50 assumed.

[2] Zeitschrift für physikalische Chemie, **11**, 529 (1893).

TABLE IX.

Lowering of Freezing Point of $FeCl_3$.

Grams in liter.	Concentration. (Molecular normal.)	Observed lowerings.	Gram molecular lowering.
1.7858	0.0110	0.0808°	7.35
3.9369	0.0242	0.1670°	6.90
5.990	0.0369	0.2455°	6.65
8.9291	0.0550	0.3434°	6.24
10.7555	0.0663	0.4101°	6.18
13.3936	0.0825	0.4928°	5.97

From these values I obtained, by graphic interpolation, the values of the molecular lowering M, and hence the values of $i = \frac{M}{1.88}$, for the dilutions indicated in Table X. Column 1 contains the concentration in gram-equivalents, Column 2 the value of i, Column 3 the equivalent initial conductivity μ_{t_0}, Column 4 the value of $\frac{\mu}{\mu_\infty}$ for barium chloride, Columns 5, 6, and 7 the values of α, β, and $\gamma = \alpha + \beta$, computed as explained above. In Column 8 is given the value of β', computed on the assumption that the hydrolysis takes place according to the reaction $FeCl_3 + 3H_2O = Fe(OH)_3 + 3\overset{+}{H} + 3\overset{-}{Cl}$, in which case equations (3), (4), and (5) become, respectively,

$$\alpha = \frac{i-1}{3} - 2\beta,$$

$$\beta = \frac{1}{1.29}\left(\frac{\mu}{120} - \frac{i-1}{3}\right),$$

$$\beta' = \frac{\mu - 120\gamma}{275}.$$

The figures can be regarded as approximate only, being undoubtedly subject to an error of several per cent. They indicate, however, the probable way the true *hydrolysis* takes place, and give an approximate measure of its amount.

TABLE X.

Equivalent concentration.	i.	μ_{t_0}.	$\frac{\mu}{\mu_\infty}$.	α.	β.	γ.	β'.
0.30	3.084	82	70.5	73	−3	70	− 1
0.15	3.394	97	77.2	77	2	79	+ 1
0.075	3.669	113	79.4	74	11	85	4
0.030	3.916	136	86.6	50	37	87	12
0.015	.....	155	88.2	35	53	..	18
0.0075	.....	171	90.8	24	67	..	22
0.0030	.....	190	94.2	10	84	..	28
0.0015	.....	199	95.8	5	91	..	31

Thus inspection of the values of β' shows that, on the assumption that the hydrolyzed hydrate is undissociated, the hydrolysis even in a 0.0015-normal solution is only 31 per cent., and that it becomes nearly constant, or increases only slowly with the dilution, a conclusion which is absurd. On the other hand, if we assume the hydrolysis to take place according to the reaction

$$\text{FeCl}_3 + \text{H}_2\text{O} = \overset{+\ +}{\text{FeOH}} + \overset{+}{\text{H}} + 3\overset{-}{\text{Cl}},$$

the hydrolytic dissociation, which is practically zero for a 0.3 equivalent normal solution, rapidly increases with the dilution, as we should expect, becoming practically complete at a dilution something beyond 1,000 liters. That the effect of the colloidal reaction is to remove the FeOH-ions from the solution, according to the reaction assumed, is shown by the fact that the *final* values of the conductivity (see Tables IV to VII) after the colloidal hydrate has formed become as great as 370, *i. e.*, they approach, and nearly reach, the value .395 of μ_∞ for hydrochloric acid. The value of β' calculated for this final value of the conductivity is about 93 per cent., showing that 93 per cent. of the ferric ions have been removed from the solution; in other words, that all of the hydrolyzed salt (91 per cent.) present on first dilution as $\overset{+\ +}{\text{FeOH}}$-ions has gone over into the colored colloidal molecular complex.

Antony and Giglio, in the paper already referred to at the beginning of this paper, have studied the change between the initial and final condition of dilute ferric chloride solutions by comparing colorimetrically the intensity of blue color produced when potassium ferrocyanide was added to the solutions before and after the colloidal reaction had taken place. As their solutions were allowed to assume their final condition at about 12° C., and as the colloidal formation increases very rapidly with the temperature, a comparison of their values with the above results is impossible. Thus they found a solution 0.00005-normal to be completely changed to colloidal hydrate after forty-eight hours. Table VII shows this to be practically the case with a 0.0001-normal solution at 25° after three hours.

ROGERS LABORATORY OF PHYSICS,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
June, 1896.

ON AN IMPROVEMENT IN THE SEDGWICK-RAFTER METHOD FOR THE MICROSCOPICAL EXAMINATION OF DRINKING WATER.

By DANIEL D. JACKSON, S.B.

Received September 24, 1896.

THE microscopical examination has assumed an important rôle in the regular analysis of drinking water since the discovery that many of the disagreeable tastes and odors often met with in waters exposed to the sunlight are due to the presence of certain minute plants or animals. Besides this important feature, the results obtained by the microscope often throw a considerable light upon the character of the organic matter contained in the water.

The gradual development of the microscopical examination of water and the improved methods employed during recent years are fully described by Professor William T. Sedgwick in "A Report of the Biological Work of the Lawrence Experiment Station."[1] The method finally decided upon, and which has come to be generally known as the Sedgwick-Rafter[2] Method, has been in use in the regular examinations of the water supplies of Massachusetts by the State Board of Health since November 6, 1890. Since that time over 11,000 quantitative microscopical analyses of water have been made in the State Laboratories at the Massachusetts Institute of Technology.

Briefly, the method employed is as follows: A definite quantity of water (usually 250 cc. for a surface water) is filtered in an ordinary chemical filter funnel through a small quantity of clean Berkshire sand. The sand selected is that which passes through a 60-mesh sieve, and will not pass through one having 120 meshes to the inch.

The organisms remain behind on the surface of the sand, while the water passes through a hole in the rubber stopper at the bottom

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[1] Report of Massachusetts State Board of Health, 1890, Part II, page 792.

[2] "Microscopical Examination of Potable Water," by George W. Rafter, Van Nostrand Science Series, 1892.

of the funnel. The hole is covered by a piece of fine bolting cloth to keep the sand in place. After the water has entirely filtered through, the sand is washed down into a test-tube by 5 cc. of water free from organisms.

After shaking thoroughly, the water containing the organisms is quickly decanted from the sand into another test-tube. The micro-organisms are then thoroughly distributed by blowing into the water through a pipette, and 1 cc. is taken for examination and placed in a covered cell such as is shown at the bottom between the two filter racks in the accompanying illustration.

The cell is 50 mm. long by 20 mm. wide, and is everywhere just 1 mm. deep. The microscope is graduated so that each field examined equals 1 sq. mm., and as the cell is 1 mm. deep, a cubic millimeter of water is examined in each field. Twenty such fields are examined, and if the amount originally taken is 250 cc., the sum total of the organisms found will be the number in 1 cc. of the water; for $\frac{250}{5} = 50$ cc. is the amount represented by the entire contents of the cell, and $\frac{20}{1000} = \frac{1}{50}$ equals the fraction of the contents examined.

Mr. G. N. Calkins, in a paper on "The Microscopical Examination of Water,"[3] gives a detailed description of the Sedgwick-Rafter Method, and of the possible sources of error which may enter into the microscopical analysis by this method.

Mr. Calkins says: "The sloping sides of a glass funnel offer a surface for the settling of organisms, and the error arising in this way may be considerable. A water free from amorphous matter and zoöglœa will filter very accurately, but a water containing these gives opportunity for error." This is undoubtedly due to the jelly-like character of the zoöglœa, and to the fact that, while adhering to the funnel sides itself, it also retains with it other organisms.

It has been the experience of the writer that not only does amorphous matter and zoöglœa readily adhere to the sides of the ordinary glass filter funnel, but the same is true of the gelatinous growths of the Cyanophyceæ and of the flocculent threads of Crenothrix.

In order to obviate this source of error as far as possible, considerable time and attention have been expended upon the construction of a new glass filter funnel which should offer to the organisms during filtration the minimum amount of surface friction.

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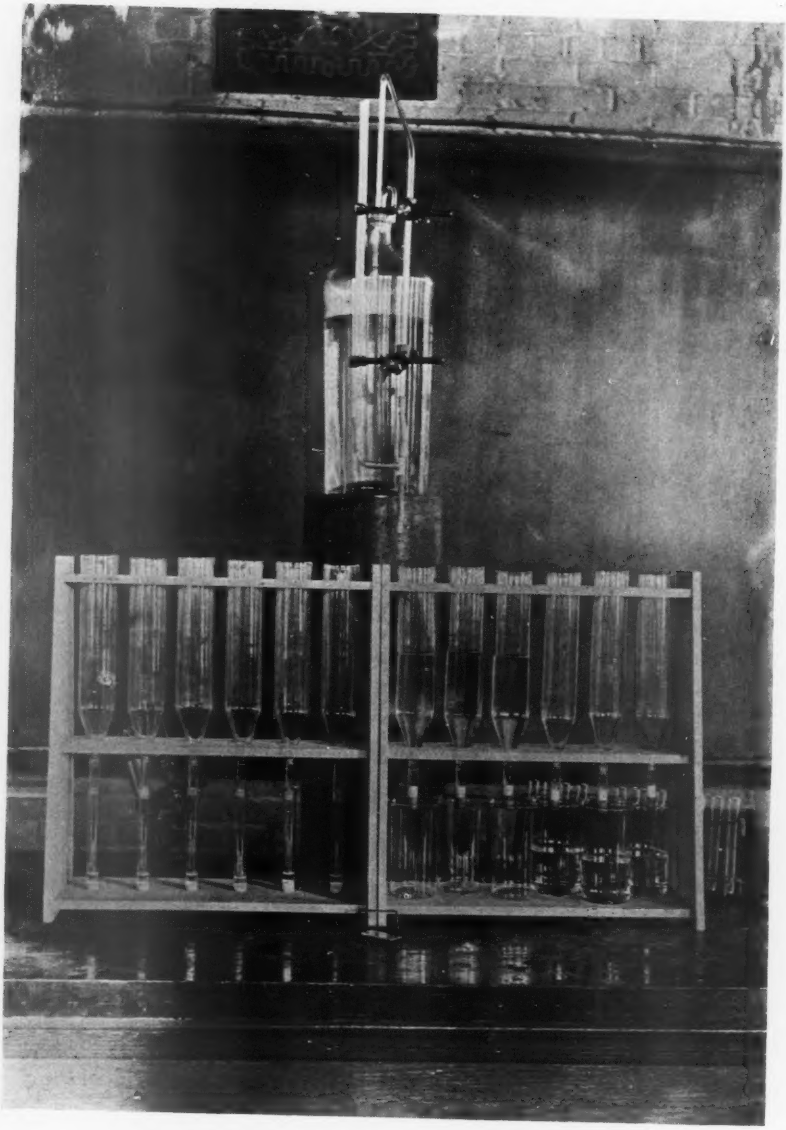
[3] Report of Mass. State Board of Health, 1891, p. 395.



Improved Apparatus for Sedgwick-Rafter Method.

It was found that the bore of the filter regulated to a large extent the rate of filtration. If the narrow tube at the bottom of the filter is increased in size, the surface of the sand in contact with the water is naturally increased and the rate of filtration is more rapid. With increased rapidity of filtration comes a diminished efficiency of the filter. On the other hand, if the bore is made too small, the rate of filtration is so slow as to entail a serious loss of time.

The filters shown in the accompanying photograph are those finally decided upon as being the most efficient. They are arranged in sets or "batteries" of six, in order to be easily handled, but each funnel can be removed from the rack when necessary. The inside diameter of the top of the funnel is 2 inches, the distance from the top to the beginning of the slope is 9 inches, and the length of the slope is 3 inches. The tube of small bore at the bottom is 2½ inches long and ½ inch in inside diameter.

The funnel should be made of comparatively thin glass, so that after the small tube is joined to the bottom annealing can be effectively accomplished. The capacity is such that 500 cc. of water may be filtered at once.

A rubber stopper with a small hole through the center is tightly fitted to the bottom of each filter funnel, so that no air space remains between the rubber and the glass. Over the hole in the rubber stopper a circular piece of fine, wet bolting cloth is placed, and on this is poured Berkshire (or quartz) sand to the depth of about three quarters of an inch. This sand should be previously selected as before described. The tube at the bottom is made long enough so that when the water is poured in the sand will not rise to the sloping sides of the funnel and become lodged there. These sloping sides should be kept clean and bright, so as to offer the least possible resistance.

After the water to be examined has passed through the filter, the beaker at the bottom is removed. The rubber stopper is then carefully taken from the lower end of the funnel so as not to disturb the wet sand, and a test-tube is quickly placed in position as shown in the filters of the left-hand rack. The arrangement shown above the filters is now used to deliver 5 cc. of distilled water into each funnel, and at the same time to wash the sand and collected organisms into the test-tubes below. Beyond this point the procedure is as before described.

In the analyses of waters by the use of the new filter funnels, considerably higher results are often obtained. This is especially noticeable in waters containing a large amount of adhesive material, as is illustrated by the accompanying table.

The new filter funnels have the advantage over the old funnels in neatness, compactness, and portability. The rate of filtration is more uniform, and the results obtained more accurate. The new funnels were put into active service in the regular microscopical examinations for the Massachusetts State Board of Health on December 1, 1895, and since that time they have been used successfully for the quantitative microscopical examination of more than seventeen hundred samples of water.

NOTE. — At the request of Professor Sedgwick, the writer has recently made numerous experiments upon the use of the centrifuge in the microscopical analysis of drinking water. Its employment for this purpose was suggested by Dr. C. S. Dolley's valuable paper on "The Planktonokrit, a Centrifugal Apparatus for the Volumetric Estimation of the Food-Supply of Oysters and Other Aquatic Animals."[1] The results thus far obtained have been more satisfactory than those obtained by the sand filter above described when delicate infusoria and rotatoria are present, but with revolutions up to 2,000 per minute, poor results were obtained if Cyanophyceæ chiefly were present. This was especially the case with Anabæna, Clathrocystis, and Cœlosphærium. The experiments will be continued.

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[1] Proceedings of the Academy of Natural Sciences of Philadelphia, May, 1896.

MICROSCOPICAL EXAMINATION OF WATER. September, 1896.

[Number of organisms per 100 cubic centimeters.]

Filter Funnel.	Old.	New.	Old.	New.	Old.	New.	Old.	New.	Old.	New.	Old.	New.
Chemist's No.	17,434	....	17,526	....	17,488	....	17,486	....	17,422	....	17,490	....
Biologist's No.	15,582	....	15,662	....	15,629	....	15,627	....	15,571	....	15,631	....
Date of collection	14	....	21	....	16	....	16	....	9	....	17	....
Date of examination,	14	....	22	....	17	....	17	....	11	....	17	....
Quantity examined	250	....	500	....	250	....	250	....	125	....	250	....
DIATOMACEÆ.												300
Asterionella	....	....	....	....	....	....	30,400	34,400	....	....	....	....
Ceratoneis	....	....	....	....	....	....	....	....	....	....	....	....
Cocconeis	....	....	....	....	....	....	2,400	2,200	....	....	....	....
Cyclotella	....	....	....	....	....	....	....	....	....	....	....	....
Cymbella	....	....	....	....	....	....	....	....	....	....	....	....
Diatoma	....	....	....	....	....	....	....	....	800	1,000	....	....
Epithemia	....	....	....	....	....	....	....	....	....	....	....	....
Fragilaria	....	....	....	....	600	400	....	....	....	....	200	200
Gomphonema	....	....	....	....	100	100	....	....	....	....	....	....
Grammatophora	....	....	....	....	....	....	....	....	....	....	....	....
Melosira	....	....	....	....	....	....	3,000	3,200	54,400	77,600	5,600	13,200
Meridion	....	....	....	....	400	400	....	....	....	800	....	....
Navicula	200	200	....	....	600	1,400	....	....	....	....	....	500
Nitzschia	....	....	....	....	....	....	....	....	....	....	....	....
Pinnularia	....	....	....	....	....	....	....	....	....	400	....	....
Stephanodiscus	....	....	....	....	....	....	....	....	....	....	....	....
Surirella	....	....	....	....	....	....	....	....	....	....	....	....
Synedra	5,200	6,400	....	....	5,800	7,800	200	1,400	....	....	4,000	7,600
Tabellaria	....	....	....	....	....	....	....	200	....	....	....	....
CYANOPHYCEÆ.												
Anabæna	13,400	15,400	....	....	....	100	200	200	452,000	604,800	....	....
Aphanocapsa	....	....	....	....	....	....	....	....	....	....	....	....
Chroöcoccus	400	400	....	....	....	....	....	....	800	800	....	....
Clathrocystis	3,200	3,600	....	....	....	....	....	....	....	....	....	....
Cœlosphærium	600	1,000	....	....	....	....	600	600	....	....	....	....
Microcystis	....	....	....	....	....	....	400	2,000	....	....	....	....
Nostoc	....	....	....	....	....	....	....	....	....	....	....	....
Oscillaria	....	....	....	....	....	....	....	....	....	....	....	....
ALGÆ.												
Arthrodesmus	....	....	....	....	....	....	600	1,000	....	....	....	....
Botrycoccus	....	....	....	....	....	....	....	....	....	....	....	....
Chlorococcus	....	....	....	....	....	....	77,600	107,200	....	....	....	....
Closterium	....	....	....	....	200	400	....	....	....	....	....	....
Conferva	....	....	....	....	....	....	....	....	....	....	....	....
Cosmarium	18,000	18,400	....	....	....	....	....	....	....	....	....	....
Desmidium	....	....	....	....	....	....	....	....	....	....	....	....
Dictyosphærium	....	....	....	....	....	....	....	....	....	....	....	....
Eudorina	....	....	....	....	....	....	....	....	....	....	....	....
Hyalotheca	....	....	....	....	....	....	....	....	....	....	....	....
Pandorina	....	....	....	....	....	....	....	....	....	....	....	....
Pediastrum	....	600	....	....	200	....	....	100	400	800	....	200
Protococcus	1,200	1,800	....	....	....	....	....	....	....	....	....	300
Raphidium	....	....	....	....	400	1,600	2,000	2,800	....	....	....	400
Scenedesmus	21,600	22,000	....	....	600	2,000	....	200	....	....	400	1,100
Sorastrum	....	....	....	....	....	....	....	....	....	....	....	....
Staurastrum	800	1,600	....	....	....	100	200	200	....	400	600	1,500
Staurogenia	....	....	....	....	800	1,200	....	800	....	....	....	500
Sphærozosma	....	....	....	....	....	....	....	....	....	....	....	400
Zoöspores	....	....	....	....	....	....	....	....	....	....	....	...
Cœlastrum	....	....	....	....	200	500	....	....	....	....	400	1,300
Xanthidium	....	....	....	....	....	....	....	200	....	....	....	....

	Old.	New.	Old.	New.	Old.	New.	Old.	New.	Old.	New.	Old.	New.
Chemist's No.	17,434	....	17,526	....	17,488	....	17,486	....	17,422	....	17,490	....
FUNGI.												
Beggiatoa	....	....	....	....	100	300	....	....	....	....	....	....
Crenothrix	....	....	1,600,000	2,000,000	....	....	....	....	....	....	....	....
Molds	....	....	....	....	....	....	....	....	....	....	....	....
Saccharomyces	....	....	....	....	....	....	....	....	....	....	....	....
Spirillum	....	....	....	....	....	....	....	....	....	....	....	...
Zoöglœa	3,500	4,000	....	....	10,000	14,000	12,000	16,000	28,000	40,000	20,000	30,000
RHIZOPODA.												
Actinophrys	....	200	....	....	....	....	....	....	....	....	....	200
Arcella	....	....	....	....	....	....	....	....	....	....	....	....
Difflugia	....	....	....	....	....	....	....	....	...	...	....	....
INFUSORIA.												
Ceratium	800	800	....	....	....	....	....	....	....	....	....	....
Ciliated infusorian	....	....	....	....	....	....	....	....	....	....	....	...
Cryptomonas	....	....	....	....	....	....	....	....	....	....	....	....
Dinobryon	....	....	....	....	....	....	....	....	....	....	54,000	53,200
Dinobryon cases	....	....	....	....	....	....	....	....	....	....	....	....
Euglena	....	....	....	....	....	....	....	....	....	....	200	200
Monas	....	....	....	....	....	100	....	800	....	....	200	300
Peridinium	....	....	....	....	....	....	....	....	....	....	....	....
Phacus	....	400	....	....	....	....	....	....	....	....	....	....
Synura	....	....	....	....	200	200	....	....	....	....	200	300
Tintinnidium	....	....	....	....	....	....	....	....	....	....	....	....
Trachelomonas	400	200	....	....	200	300	400	600	....	....	200	100
Uvella	....	....	....	....	....	....	....	....	....	....	....	....
Uroglena	....	....	....	....	....	....	100	100	....	....	....	....
Vorticella	....	....	....	....	....	....	....	....	....	....	....	....
Mallomonas	....	....	....	....	200	600	200	200	....	....	....	....
Raphidomonas	....	....	....	....	....	....	....	400	....	....	....	....
VERMES.												
Anguillula	....	....	....	....	....	....	....	....	....	....	....	....
Anurea	....	200	....	....	....	....	....	....	....	....	....	100
Asplanchna	....	....	....	....	....	....	....	....	....	....	....	....
Monocerca	....	....	....	....	....	....	....	....	....	....	....	....
Polyarthra	....	200	....	....	....	....	....	....	....	....	....	100
Rotatorian ova	200	200	....	....	....	....	....	200	....	400	....	....
Rotifer	....	....	....	....	....	....	....	200	....	....	....	....
Triarthra	....	....	....	....	....	....	....	....	....	....	....	....
CRUSTACEA.												
Bosmina	....	....	....	....	....	....	....	....	....	....	....	....
Cyclops	....	....	....	....	....	....	....	....	....	....	....	....
Daphnia	....	....	....	....	....	....	....	....	....	....	....	....
Entomostracan ova	....	....	....	....	....	....	....	....	....	....	....	....
Moina	....	....	....	....	....	....	....	....	....	....	....	....
MISCELLANEOUS.												
Amorphous matter	pr.	pr.	....	....	pr.	pr.	abd.	abd.	pr.	pr.	abd.	abd.
Mites	....	....	....	....	....	....	....	....	....	....	....	....
Sponge spicules	....	....	....	....	....	....	....	....	....	....	....	....
Starch grains	....	....	....	....	....	....	....	....	....	....	....	....
Vegetable tissue	....	....	....	....	pr.	pr.	pr.	pr.	....	....	....	....
Iron	....	....	abd.	abd.	....	....	....	....	....	....	....	....
TOTAL ORGANISMS	69,500	77,600	1,600,000	2,000,000	20,600	31,500	130,300	175,200	536,400	727,000	86,000	112,000
TOTAL GENERA	14	19	1	1	16	18	15	24	6	10	12	22

NOTE.—Zoöglœa unit = 2,500 square microns = .0025 square millimeters.

EXPERIENCE WITH THE SEDGWICK-RAFTER METHOD AT THE BIOLOGICAL LABORATORY OF THE BOSTON WATER WORKS.

BY GEORGE C. WHIPPLE, S.B.,

Received October 2, 1896.

IN connection with Mr. D. D. Jackson's paper on "An Improvement in the Sedgwick-Rafter Method of Microscopical Examination of Drinking Water,"[1] it may be interesting to note some experiences with that method at the Biological Laboratory of the Boston Water Works.

The Sedgwick-Rafter Method has been used in the Boston Water Works Laboratory at Chestnut Hill Reservoir since its establishment in 1889, and from that time to the present more than 19,000 quantitative microscopical examinations of water have been made. Most of the samples examined have been those collected from the streams, storage reservoirs, aqueducts, and service pipes of the water supply, but many examinations were made in connection with the filtration experiments conducted during the years 1891 to 1894. The character of the samples has therefore varied over a wide range, from waters free of microscopical organisms to those rich in algæ and infusoria. In all this varied work the method has seldom failed to give trustworthy record of the animal and plant forms present, and the information thus obtained concerning the condition of the water has been of material assistance to the superintendent in the management of the supply.

In common with almost all analytical processes, the Sedgwick-Rafter Method involves some sources of error. These have been carefully studied at various times in the Boston Water Works Laboratory in order to determine the precision of the method as ordinarily used. In the main, the results of the experiments made by

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[1] This volume, pp. 271–274.

the writer have corroborated those obtained by Mr. Gary N. Calkins[1] in 1892, but in some respects they have been different.

The most important errors in the method are those involved in the concentration of the sample. They may be designated as follows:

1. The Funnel Error, or error caused by the organisms adhering to the sides of the funnel.
2. The Sand Error, or error caused by the organisms passing through the sand.
3. The Decantation Error, or error caused by the organisms adhering to the particles of sand and by the water used in washing the sand being held back by capillarity during the process of decantation.

The funnel error varies greatly, according to the character of the water filtered. It is highest in the case of samples rich in Cyanophyceæ and "amorphous matter." These being of a somewhat gelatinous nature adhere readily to the glass, making a rough surface on which other organisms lodge. If the funnel is wet when the sand is put in, some of the sand grains are also liable to adhere to the glass walls of the funnel; careful manipulation, however, will avoid this. Samples which filter slowly, and which for that reason give the organisms good opportunity to settle upon and become attached to the glass, show the greatest funnel errors, and indeed we may almost say that the funnel error is proportional to the time of filtration.

By filtering a sample in the usual manner, and afterwards washing the sides of the funnel with distilled water and ascertaining the number of organisms thus washed from the glass, Mr. Calkins found that the funnel error varied from 0.09 per cent. to 1.9 per cent., the average being 0.3 per cent. Similar experiments made by the writer have given somewhat larger errors than these, the average for twenty-one representative samples being 0.96 per cent. for the organisms and 2.9 per cent. for the amorphous matter. The greatest error found during the experiments was 11.3 per cent. for the organisms and 16.3 per cent. for the amorphous matter, but not infrequently the errors exceed even these figures. By employing forced filtration (*i. e.*, using the aspirator), and thus lessening the time required for the water

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[1] Calkins, Gary N. "The Microscopical Examination of Water," Massachusetts State Board of Health. 23d Annual Report.

to pass through the sand, the average funnel error was reduced to 0.24 per cent. for the organisms and 0.8 per cent. for the amorphous matter. Forced filtration, however, has certain objections, and is not ordinarily advisable. The best method of minimizing the funnel error appears to be the use of tubular funnels, like those designed by Mr. Jackson. Funnels of this kind are now in use at the Boston Water Works Laboratory. Besides having the advantage of greater efficiency, they are neater in appearance, occupy less room, and are more conveniently handled.

The amount of the sand error depends upon the character of the organisms, upon the size of the sand grains and the depth of the sand. In selecting a sand to be used, two opposing conditions must be adjusted. The sand must be fine enough to form an efficient filter, and yet the grains must be large enough to settle readily in the decantation tubes. Experience has shown that for the samples received at the Boston Water Works Laboratory a sand having the following mechanical analysis satisfactorily fulfills the conditions :

Sieve marked.	Size of separation of this sieve. (Millimeters.)	Quantity of sand passing. (Per cent. of total weight.)
40	0.38	100
60	0.28	80
80	0.20	60
100	0.16	22
120	0.14	4

According to the nomenclature of the Massachusetts State Board of Health, this sand has an "effective size" of 0.15 mm. and a "uniformity coefficient" of 1.33. As to the amount of sand necessary, numerous experiments have shown that if the depth is less than 1.5 cm. the sand error is likely to be large; but with depths greater than 2 cm. the error is practically independent of the depth. In actual practice, using the sand above referred to, the error from organisms passing through the filter ought not to exceed 2 per cent., unless the samples contain organisms which are very minute. Most of the organisms which pass through the sand do so during the early part of the filtration, before the sand has become compacted. If, before the sample is poured into the funnel, the sand is first compacted by rapidly passing through it some distilled water, using the aspirator to increase the pressure, the sand error may be much reduced.

The decantation error is one of considerable importance, depending to a great extent upon care in manipulation. It arises from the fact that when the attempt is made to separate the organisms from the sand by agitating with distilled water in one test-tube and rapidly decanting into a second tube, some of the organisms remain behind attached to the sand grains.

Mr. Calkins, in his experiments, first washed the sand with 5 cc. of distilled water and decanted, then rewashed with 5 cc. and decanted into a second tube, the number of organisms found in the second washing being taken to represent the decantation error. In this way he observed errors varying from 1.5 to 15.5 per cent., the average being 7.5 per cent. In the writer's experiments the sand was washed first with 3 cc. and then with 2 cc. of distilled water, both portions being decanted into the same tube, experience having shown that this double washing is more effective in cleaning the sand. The sand was then rewashed with 5 cc., which was decanted into a separate tube and examined to determine the decantation error. The results showed errors ranging from 0.1 to 12.0 per cent. for the organisms and 0.5 to 6.9 per cent. for the amorphous matter. The average of twenty-four observations gave 2.5 per cent. for the organisms and 3.0 per cent. for the amorphous matter, figures which are noticeably lower than those obtained by Mr. Calkins.

There is another source of error in the decantation of a sample which more than offsets the one just mentioned, and which has not generally been taken into account; it tends to give results which are too high. It is caused by the fact that some of the distilled water used in washing the sample is left behind in the sand and on the walls of the test-tube, so that the organisms when decanted receive too high a degree of concentration, for it has been found that the sand retains a larger percentage of water than of organisms. To avoid this error as much as possible, the washing of the sand should take place immediately after the sample has filtered, and the decantation tubes should be used moist instead of dry. The amount of this error is likely to reach 5 or even 10 per cent. unless great care is used in manipulation.

Very frequently samples are received at the laboratory which are so filled with organisms or with amorphous matter that filtration is effected with great difficulty. The sand becomes clogged, and a dense scum is formed, almost if not quite impervious to water. When this occurs it is necessary either to stir the sand from above or to connect the lower end of the funnel with an aspirator, or filter pump. There are objections to both these proceedings, but the writer believes the latter to be by far the better one. It increases the sand error but little, and by lessening the time of filtration decreases the funnel error materially. Indeed, so great is the improvement in this respect, that the aspirator might be recommended for general use were it not for the danger of delicate organisms being crushed on the sand by the increased pressure. As it is, its use should be restricted to cases of emergency where it is necessary to overcome the clogging of the sand, or when for some reason it is desired to effect a rapid filtration. For these purposes the aspirator forms a valuable part of the apparatus.

In order to determine the comparative effect of stirring the sand and of using the aspirator, six samples, differing widely in the number and character of their contained organisms, were filtered: first, by gravity without stirring; second, by gravity, the sand being stirred; and third, by using the aspirator. The following average sand errors were obtained:

	Method of filtration.	Percentage sand error.
1.	Gravity without stirring	1.3
2.	Gravity, the sand being stirred . . .	2.1
3.	Using the aspirator	1.4

Thus it will be seen that stirring the sand almost doubles the sand error, while the use of the aspirator increases it but slightly.

The reduction of the funnel error when the aspirator is used is shown by the following table:

Method.	Number of examinations.	Average time of filtration. (Minutes.)	PERCENTAGE FUNNEL ERRORS.	
			Organisms.	Amorphous matter.
Gravity	9	76	0.96	2.9
Aspirator	11	4	0.24	0.8

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

VI.

Received June 12, 1896.

STEAM AND HYDRAULICS.

DESCRIPTION AND RESULTS OF A 50-HOUR TEST MADE ON THURSDAY, FRIDAY, AND SATURDAY, MAY 7, 8, 9, 1896, AT THE WEST END STREET RAILWAY'S POWER STATION, NEAR SULLIVAN SQUARE, CHARLESTOWN, MASS.

This test was made by ninety students of the senior class of the Massachusetts Institute of Technology as a part of the regular work of the Engineering Laboratories, and was under the direction of the instructing staff of the laboratories.

Through the courtesy of Mr. C. F. Baker, master mechanic of the road, excellent opportunities to collect instructive data were given us.

The 50-hour run was divided into five watches of ten hours each, eighteen students working on each watch.

The object of the test was to determine the evaporation of the boilers per pound of coal, the coal for the plant per indicated horse power of the main engines, and also the coal per kilowatt and per electrical horse power.

Besides the observations needed to calculate the above much other data of great value was obtained. As there were something like 20,000 observations, or about 80,000 figures, taken during the test, it was thought advisable to print only the totals and averages of the different readings.

DESCRIPTION OF PLANT.

Steam is supplied by three Babcock & Wilcox boilers, each of 500 nominal horse power (A. S. M. E. rating).

These discharge their gases into an inclined brick flue about 35 feet long at the back of the boilers. This flue leads either into a Green economizer and from thence to the stack or into a straight flue by the side of the economizer also leading into the stack. By means of dampers the gases can be turned through either of these passages.

Boilers No. 1 and No. 2 are set without any space between them. Between Boilers No. 2 and No. 3 there is a space of about four feet.

The steam piping is so arranged that either Boilers No. 1 or No. 2 can supply Engine No. 1, while Boiler No. 3 supplies Engine No. 2, or the entire battery can be made to deliver into the main.

During the test Boiler No. 1 was shut down, two boilers being all that are needed to do the work.

The stack into which these exhausted is 200 feet tall, with an internal diameter of core of 10 feet.

The engines are Allis-Corliss cross-compound, with independent jet-condensing pumps.

The parts of the engine are so designed that either cylinder can be run at 1,000 I. H. P. As either side can be made to run the engine there is but little loss of running time on account of repairs.

Engines No. 1 and No. 2 are 26, 50 x 48, and run at a speed of about 90 revolutions per minute. The main engines and air-pump engines were built by E. P. Allis, of Milwaukee.

The fly wheel of each engine is built up of mild steel plates bolted to a cast-iron hub, the whole weighing something over 40 tons.

The generator is of the multipolar direct connected type, and was built by the General Electric Company. It is known as an M. P. 10–800–90, contains 10 poles, and is of 800 kilowatt nominal capacity at 90 revolutions.

It is designed to give 500 volts at no load, and is over compounded to give 550 volts at full load when delivering 1,450 amperes.

The switchboard is of the General Electric type, with eight feeder panels and four generator panels.

Steam is taken by each engine through a Stratton separator located beneath the engine. The drip from the separator is run through a coil of pipe in the first receiver, and thence trapped directly into the suction of the feed pump.

There is a small amount of drip from the working side of the receiver which is thrown away. The steam exhausted by the air-pump engine is discharged into the receiver.

Feed water is taken from the city main first through National heaters in the exhaust pipe of each main engine, these heaters being situated between the low-pressure cylinders and the air pumps. From here it passes to the suction of the feed pump, the discharge from the traps on the separator drips entering this pipe and mingling with the water on the way to the pump. After leaving the pump the feed water enters a secondary heater or feed-pump heater, as it is called in these pages to distinguish from the other heaters. This heater is fed with the exhaust steam from the feed pump. It was found that this heater was large enough to condense all of the exhaust steam, and so during the test the amount of steam used by the feed pump was determined by weighing the drip from the steam side of the heater.

After leaving the heater the water passes through a Green economizer rated at 2,000 H. P. before entering the boiler.

ARRANGEMENTS MADE FOR TESTING AND METHODS USED.

The pipe ordinarily supplying the feed water from the city main was broken and the water weighed in four large barrels. From these it was discharged as required into two reserve barrels, which delivered through a wrought iron pipe to the National heaters in the exhaust pipes. These barrels were supported on a platform in the engine room, the platform being high enough above the floor to give a head of five feet of water in the reserve barrels above the entrance to the heaters in the exhaust pipes.

Temperatures of feed water were taken at such places as to enable us to note the gain due to different heaters and in different sections of the economizer.

The drips from the working sides of the receivers were caught and weighed, as was also the drip from the pump heater, this latter quantity being the steam used by the feed pump.

The drips from the two separators were caught in two calibrated steel cylinders, 18″ in diameter and 4′–6″ high, having gauge glasses on the sides. Whenever these filled the reading of the upper level was taken and the discharge valve opened, a record being kept of the time this valve was open, so that allowance could be made for

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NOTE.—Quite a full description of the plant together with drawings of the engines, boilers, and stack, can be found in Vol. xii, No. 3, of Street Railway Journal.

the drip lost while discharging. As soon as the valve was closed the lower level was taken. The drips were discharged into the suction pipe of the feed pump. Owing to the fact that this hot water was liable to make the pump race, it was necessary to stop the feed pump whenever the drips were blown out. The water then backed up into the reserve barrels.

Counters were attached to both main engines and both air pumps.

Indicator cards were taken from each engine and air pump every twenty minutes. The cards were taken on the two engines alternately, the times being ten minutes apart. Crosby indicators were used on Engine No. 1 and Air Pump No. 1, and Thompson indicators on Engine and Air Pump No. 2.

The indicator rigs used on the main engines were the common "lazy tongs" pantograph, a separate set being used for each cylinder. The air-pump indicators were run by a cord attached to an eccentric pin in the end of each pump shaft.

The test was started with clean fires and everything running. The condition of the fires in Boilers No. 2 and No. 3 was noted, as were also the levels in the gauge glasses. At the closing of the test the fires were clean and were brought as nearly as possible to the condition at starting. Levels in the gauge glasses were also made right.

Samples of steam were taken by throttling calorimeters placed close to the discharge outlet of each boiler.

The temperature of the steam was taken instead of the pressure. By using long thermometer cups the temperatures could be depended upon to $\frac{5}{10}^\circ$ C., while it would be impossible to rely upon a gauge within one pound.

A machine ammeter of the Weston shunt type and a General Electric Wattmeter were connected with each machine, and were mounted on the switchboard.

A station ammeter of same type upon the switchboard measured the total current supplied by the station.

A Weston voltmeter, also mounted on the switchboard, was arranged to be connected to either machine or the main bus bar.

These instruments constitute a part of the regular equipment of the station. In addition a Weston shunt ammeter was connected to No. 1 machine, and a portable Weston voltmeter to give main voltage.

The shunt field circuits of both machines were opened and Weston ammeters inserted to indicate the field current.

The equalizer circuit between the machines was opened and a shunt ammeter, calibrated to read in either direction, was connected to show the direction and quantity of current flowing between the two machines.

The shunt field circuit does not pass through the other instruments.

All station instruments were calibrated by the General Electric Company three weeks before the test. These instruments were not recalibrated at the Institute.

The constant given by the makers for the Wattmeter is 300.

REMARKS.

At 10.05 P.M. Thursday the joint in the feed pipe at bottom of feed-pump heater blew out. The valves were immediately changed so as to cut this heater out. There was an amount of weighed water lost equal to the contents of the heater. This amount was determined after the test and allowance made for the same. The exhaust from the feed pump was, of course, turned outboard.

The joint was packed over, and at 11.25 the feed was turned through the heater again, and the exhaust steam was turned in at 11.27.

At 12.50 A.M. Friday part of the load on Engine No. 1 was transferred to Engine No. 2, leaving No. 1 light, as the commutator had been sparking badly for about two hours.

At 7.30 A.M. water backed up and ran over reserve barrels while blowing down separator-drip reservoir, and about 100 pounds of water were lost.

Barrel for condensed steam from feed pump ran over about 2.40 P.M. Friday. About 25 pounds of water were lost.

Water backed up again in reserve barrels at about 4 P.M. Friday. Loss of about 75 pounds.

On Friday evening, on account of the bad sparking of the commutator on No. 1 Dynamo, it was deemed advisable to shut the engine down and smooth up the commutator, especially as at this time the engines were running light. Accordingly, No. 2 Boiler was disconnected from the battery at 9.51 P.M. and used for No. 1 Engine and pump only. No. 3 Boiler now supplied the steam for No. 2 Engine and air pump and the feed pump, No. 2 taking about twice its former load.

The level in No. 2 Boiler was run up about 7½″ above the center of the drums before cutting out. No water was put into this boiler until 2.17 A.M. Saturday, at which time the level had dropped, due to the blowing of the safety valves, to ¼″ below the center of the boiler. 11,936 pounds of water were now put in. While raising the level the feed valve to No. 3 Boiler was closed and record kept of the weight of water pumped into No. 2, and also of the steam used by feed pump while doing this.

At 4.20 A.M. Saturday the boiler was put into the battery again. The water level at this time was 6¾″ above the center of the drums.

The amount of water used by this boiler while shut out is equal to the amount put in plus the amount needed to bring the water level back to the level at the time of cutting out. This latter amount was estimated to be about 800 pounds, giving a total of 12,756 pounds.

The amount of coal used by this boiler while cut out was also recorded, but, inasmuch as this opportunity was taken to give the fires a thorough cleaning, it was deemed fairer to figure the amount of coal required from the water put in and the rate of evaporation as determined from the entire test.

The amount of coal and water used by the boiler while cut out is deducted from the amount required by the plant, account, of course, being taken of the time the engine was not working.

Engine No. 1 was slowed down at 9.53 P.M. Friday. At 10.11 it was shut down entirely, and started again at 10.22 and run slowly until 4 A.M., while the commutator was being sandpapered. It was then stopped to clean the commutator and adjust the brushes. At 5.03 the engine was started again and the load thrown onto the dynamo at 5.10.

While the engine was slowed down the safety valves on No. 2 Boiler were blowing for a considerable time.

At 2 A.M. Saturday, while Boiler No. 2 was cut out, the pressure in No. 3 dropped to 95 pounds, due to No. 2 Engine working beyond the capacity of the boiler, the fireman not having had a chance to clean fires before the load was thrown on. The central station, which had been shut down, then started up and took part of the load, and at 2.15 the pressure was back to 160 pounds.

STATIONS FOR TEST MAY 7, 8, 9, 1896, CHARLESTOWN POWER STATION, WEST END RAILROAD.

(1) Coal for Boilers No. 2 and No. 3. Barometer. Outside air. Temperature of fire room. Draught at base of stack. Temperature of feed water entering economizer.

(2) Feed water thermometers, entering Boilers No. 2 and No. 3. Temperature of feed water leaving economizer. Temperature at thermometers Nos. 4, 3, 2, 1 on economizer. Temperature of gases leaving economizer.

(3) Temperatures of steam, Boilers Nos. 2 and 3. Temperature of hot gases. Draught pressure and both calorimeters noting time calorimeters were in use.

(4) (5) Weigh water for boilers (four barrels each of 1,200 pounds capacity).

(6) Drip from Separator No. 1. Time and gong every ten minutes. Temperature of feed at pump. Temperature of feed leaving pump heater. Ring two sets of bells, alternating every ten minutes, thus, ... — . . — . ; ten minutes later, . . . — . . — . , etc.

(7) Drip from separator on No. 2 Engine. Counter on No. 2 Air Pump. Temperature of hot and cold condensing water of both pumps. Temperature of exhaust steam.

(8) Weight of drip from receivers on Engines No. 1 and No. 2. Also weight of steam from feed-pump heater. Temperature of feed water leaving heaters in exhaust pipe of Engines No. 1 and No. 2.

(9) Counter on No. 1 Air Pump. Cards on No. 1 and No. 2 Air Pumps. Planimeter.

(10) Temperature of cold water in reserve barrels. Pressure in receivers and vacuum in condensers of Engines No. 1 and No. 2. Measure length of cards, etc.

(11) (12) (13) Counter. Cards. Planimeter. Measure cards, etc., for both engines.

(14) General log. (Complete record of all observations.)

(15) Current Dynamo No. 1 (Main & Field) every ten minutes. Assists in work on cards.

(16) Current Dynamo No. 2 (Main & Field) every ten minutes. Assists in work on cards.

(17) Voltmeter every ten minutes. Works on cards.

(18) Work on cards, all engines. Planimeter, length, and per cent. cut-off.

DATA AND RESULTS OF TEST ON WEST END POWER STATION AT CHARLESTOWN.

Areas and Weights.

	Boiler No. 2.	Boiler No. 3.
Total heating surface	5,372 sq. ft.	5,372 sq. ft.
Total grate surface	88.1 sq. ft.	88.1 sq. ft.
Total coal fired	48,345 lbs.	57,190 lbs.
Coal drawn from grate	200 lbs.	60 lbs.
Total coal burned	48,145 lbs.	57,130 lbs.
Weight of ashes, clinkers, etc.	4,195 lbs.	5,000 lbs.
Total combustible	43,950 lbs.	52,130 lbs.
Estimated weight of water in coal		2.7%
Total coal (including moisture)		105,275 lbs.
Coal used by Boiler No. 2 while shut off (figured from water put in and the rate of evaporation). (See remarks.)		1,345 lbs.
Total coal during test		103,390 lbs.
Total ash during test		9,080 lbs.
Total combustible during test		94,850 lbs.
Total water weighed in barrels (50 hours)		957,995 lbs.
Returns from separator drip cans (50 hours)		Engine No. 1, 20,310 lbs. Engine No. 2, 21,590 lbs.
Total water put into boilers by feed pump (50 hours)		999,895 lbs.
Weight of water put into Boiler No. 2 while shut off, including allowance made for difference of level when boiler was connected from that at shutting off		12,755 lbs.
Steam used by feed pump feeding No. 2 while shut off		285 lbs.
Total water during test		987,140 lbs.

Weights.

Drip from working side of receiver per hour	Engine No. 1, 362.4 lbs. Engine No. 2, 229.3 lbs.
Steam used by feed pump	32,398 lbs.
Steam used by both calorimeters	2,646 lbs.
Quality of steam at boilers; mean of calorimeter tests	Boiler No. 2, .990 lbs. Boiler No. 3, .990 lbs.
Average	.990 lbs.
Steam required by plant, both engines running, Engine No. 1 running 42.72 hours, and Engine No. 2 running 50 hours	984,494 lbs.
Coal for plant (deducting coal required for steam used by calorimeter, 278 lbs.),	103,652 lbs.
Coal per hour for plant, figured by dividing above by average time both engines were running $= \frac{50 + 42.72}{2} = 46.36$	2,236 lbs.

Temperatures.

Temperature boiler room	81.6° F.
Temperature outside air	57.9° F.
Temperature steam at boiler	No. 2, 179.4° C. No. 3, 177.2° C.
Temperature cold feed water at barrels	16.5° C.
Temperature leaving heaters in exhaust pipe	No. 1, 60.1° C. No. 2, 62.4° C.
Temperature entering feed pump	59.9° C.
Temperature leaving heater supplied with feed pump steam	77.5° C.
Temperature entering economizer	75.9° C.
Temperature after passing through 30 tubes of economizer	73.1° C.[1]
Temperature after passing through 150 tubes of economizer	77.7° C.
Temperature after passing through 270 tubes of economizer	79.9° C.

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[1] Drop in temperature due to leakage of cold air.

Temperature after passing through 410 tubes of economizer	87.1° C.
Temperature leaving economizer (560 tubes)	91.6° C.
Temperature entering boilers	No. 2, 94.0° C. No. 3, 97.8° C.
Temperature exhaust steam from engines close to condensers	No. 1, 137.6° F.
Temperature injection water entering condenser	No. 1, 12.5° C. No. 2, 13.0° C.
Temperature injection water leaving condenser	No. 1, 25.4° C. No. 2, 30.4° C.
Temperature drip from separator	No. 1, 171.1° C. No. 2, 142.4° C.
Temperature hot flue gases at back of boiler	213.7° C.
Temperature flue gases leaving economizer	152.2° C.

PRESSURES AND TIME.

Barometer	30.305
Vacuum in condensers	No. 1, 12.04 lbs. No. 2, 12.26 lbs.
Pressure in receivers	No. 1, 8.3 lbs. No. 2, 7.9 lbs.
Draught at back of boilers (inches of water)	Average, .2997 Maximum, .602
Draught at base of stack (inches of water)	Average, .3727. Maximum, .656
Time starting test	Thursday, 3.30 P.M.
Time stopping No. 1 Engine	Friday, 9.53 P.M.
Time starting No. 1 Engine (loaded)	Saturday, 5.10 A.M.
Time cutting No. 2 Boiler out	Friday, 9.51 P.M.
Time putting No. 2 Boiler in again	Saturday, 4.20 A.M.
Time ending test	Saturday, 5.30 P.M.
Total time Engine No. 1 was working	42 hrs. 43 mins.
Total time Engine No. 2 was working	50 hrs.
Total time Boiler No. 2 was working	43 hrs. 31 mins.
Total time Boiler No. 3 was working	50 hrs.
Total time feed-pump heater was cut out	1 hr. 20 mins.

REVOLUTIONS.

Total revolutions No. 1 Air Pump,	42.67 hours				156,598	
Total revolutions No. 2 Air Pump,	49.33 hours				178,451	
Average M. E. P. Pump No. 1		H. E.,	17.46	C. E.	30.25	
Average M. E. P. Pump No. 2		H. E,	18.94	C. E.	24.56	
H. P. Pump No. 1		H. E.,	4.66	C. E.	8.17	Total, 12.83
H. P. Pump No. 2, H. E.			5.22	C. E.	6.54	Total, 11.76

Total revolutions Engine No. 1,	First,	9.67 hours	50,533
	Second,	12.00 hours	63,358
	Third,	8.67 hours	44,903
	Fourth,	7.00 hours	Not running.
	Last,	12.33 hours	64,128
Total time		42.67	222,922 total revolutions.

Total revolutions Engine No. 2,	First,	9.67 hours	50,501
	Second	12.00 hours	62,882
	Third,	8.67 hours	44,586
	Fourth,	7.00 hours	35,831
	Last,	12.33 hours	64,302
Total time		49.67	258,102 total revolutions.

M. E. P. AND PER CENT. OF CUT-OFF.

M. E. P. Engine No. 1.

Time.	High.		Low.	
	H. E.	C. E.	H. E.	C. E.
9.67	32.18	27.75	9.92	7.72
12.00	17.62	14.64	7.38	5.79
8.67	34.93	26.55	9.94	8.44
7.00 not running.	.....	.....	....	....
12.33	30.98	23.92	9.21	7.19
Average M. E. P. per hour entire run	28.17	23.59	9.00	7.18

M. E. P. Engine No. 2.

Time.	High.		Low.	
	H. E.	C. E.	H. E.	C. E.
9.67	29.43	16 04	9.35	9.84
12.00	23.71	9.84	8.29	8.78
8.67	37.75	23.99	10.29	10.61
7.00	35.80	22.89	10.58	10.83
12.33	30.87	16.16	8.77	9.04
Av. M. E. P. for entire test,	30.74	16.80	9.28	9.64

Per Cent. of Cut-off Engine No. 1.

Time.	High.		Low.	
	H. E.	C. E.	H. E.	C. E.
9.67	15.21	11.22	33.84	21.07
12.00	7.65	6.25	30.63	20.78
8.67	18.66	13.45	36.58	23.73
7.00	.....	....	.....	.....
12.33	16.70	11.52	33.42	21.40
Average entire test . .	14.13	10.35	33.74	21.61

M. E. P. AND PER CENT. OF CUT-OFF.—*Continued.*

Per Cent. of Cut-off Engine No. 2.

Time.	HIGH.		LOW.	
	H. E.	C. E.	H. E.	C. E.
9.67	18.82	9.38	29.51	27.35
12.00	15.84	7.07	26.36	25.21
8.67	23.17	13.59	36.33	31.82
7.00	24.85	15.75	37.64	37.80
12.33	17.62	8.82	30.01	28.62
Av. entire test . . .	19.39	10.35	31.30	29.36

ELECTRICAL DATA.

DYNAMO NO. 1.			DYNAMO NO. 2.					
Time.	Main current.	Field current.	Time.	Main current.	Field current.	Time.	Total current.	Voltage.
9.67	768.4	7.715	9.67	864.8	6.756	9.67	1,633.2	566.02
12.00	559.4	7.559	12.00	696.5	6.949	12.00	1,255.9	561.05
8.67	870.8	8.168	8.67	934.6	7.306	8.67	1,805.4	565.33
7.00	....	....	7.00	949.0	6.782	7.00	949.0	566.98
12.33	745.9	8.056	12.33	790.3	7.267	12.33	1,536.2	570.11
Av. entire test. .	724.4	7.861	Av. entire test. .	732.2	7.060	Av. entire test. .	1,456.6	565.80

Wattmeter Readings.

Time.	DYNAMO NO. 1.		DYNAMO NO. 2.	
	Reading.	Difference.	Reading.	Difference.
Thursday, 3.30 P.M. . . .	2,845,500		3,580,290	
Friday, 12.30 A.M. . . .	2,983,320	137,820	3,729,120	148,830
Friday, 12.30 P.M. . . .	3,114,180	130,860	3,890,720	161,600
Friday, 9.30 P.M.	3,257,120	142,940	4,058,800	168,080
	Shut down till 5.10.			
Saturday, 5.30 A.M. . . .	3,271,950	14,830	4,201,700	142,900
Saturday, 5.30 P.M. . . .	3,446,080	174,130	4,389,830	188,130
		600,580		809,540

SIZES OF ENGINES.

Sizes of Engines Nos. 1 and 2.

Diameter high.	Diameter rod.	Diameter low.	Diameter rod.	Stroke.
26″	5″	50″	6″	48″

Air Pump Engines Nos. 1 and 2.

Diameter Cylinder.	Diameter rod.	Stroke.
12″	$2\frac{3}{16}$″	16″

BOILER SIZES.

There are 21 sections in each boiler, each section containing

12 tubes, 4″ outside diameter, 18′ 6″ long.
1 tube, 4½″ outside diameter, 5′ 8″ long.
2 tubes, 4½″ outside diameter, 0′ 10″ long.
1 tube, 4½″ outside diameter, 0′ 10″ long.
1 face of front and rear headers; estimated total for the 21 sections, 21.99 square feet.
Deduct for smoke consuming tile 21 tubes, ½ circumference covered with 3 tiles, each 18″ long, and 21 tubes with 2 tiles, each 18″ long.
3 drums bricked at center of diameter, 42″ inside diameter, $\frac{7}{16}$″ plate.
21 feet of length of drum exposed to fire.
Smoke connection, 72″ x 42″.
Grate, 7′ x 12′ 7″.
Air space, 40% of grate surface.
Smoke connection, 21 square feet.
Grate surface, 88.08 square feet.
Heating surface, 5,344 square feet.

RESULTS.

Water apparently evaporated per pound of coal	9.498 lbs.
Equivalent from and at 212° F. per pound of coal, not including economizer	9.91 lbs.
Equivalent from and at 212° F. per pound of coal, including economizer	10.27 lbs.
Equivalent from and at 212° F. per pound of combustible, including economizer	11.25 lbs.
Coal per square foot of grate per hour, No. 2	12.57 lbs.
Coal per square foot of grate per hour, No. 3	12.97 lbs.
H. P. No. 1 Air Pump	12.83
H. P. No. 2 Air Pump	11.76

H. P. No. 1 Engine.

	1st. 9.67 hours.	2d. 12 hours.	3d. 8.67 hours.	4th. 7 hours.	5th. 12.33 hours.
H. H.	180.43	99.78	194.11	......	172.78
H. C.	149.84	79.85	142.09	......	128.47
Total	330.27	179.63	336.20	......	301.25
L. H.	205.70	154.56	204.28	......	189.95
L. C.	157.77	119.52	170.96	......	146.16
Total	363.47	274.08	375.24	......	336.11
Total H. and L.	693.74	453.71	711.44	......	637.36

Average H. P. No. 1 Engine 618.34

H. P. No. 2 Engine.

	1st. 9.67 hours.	2d. 12 hours.	3d. 8.67 hours.	4th. 7 hours.	5th. 12.33 hours.
H. H.	164.91	133.26	208.30	196.55	172 63
H. C.	86.55	53.26	127.48	121.03	87.03
Total	251.46	186.52	335.78	317.58	259.66
L. H.	193.76	172.32	209.98	214.82	181.37
L. C.	200.97	179.87	213.40	216.73	184.26
Total	394.73	352.19	423.38	431.55	365.63
Total H. and L.	646.19	538.71	759.16	749.13	625.29

Average H. P. No. 2 Engine 648.65

RESULTS. — *Continued.*

No. 1 Engine.

	1st. 9.67 hours.	2d. 12 hours.	3d. 8.67 hours.	4th. 7 hours.	5th. 12.33 hours.
Kilowatts	434.93	313.85	492.29	......	425.24
H. P. output	583.02	420.71	659.91	......	570.04

Average kilowatts, 50 hours (calculated)	409.87
Average H. P. output, 50 hours	549.42

No. 2 Engine.

	1st. 9.67 hours.	2d. 12 hours.	3d. 8.67 hours.	4th. 7 hours.	5th. 12.33 hours.
Kilowatts	489.49	390.77	528.35	538.06	450.56
H. P. output	656.16	523.82	708.25	721.26	603.97

Average kilowatts, 50 hours (calculated)	414.28
Average H. P. output, 50 hours	555.33
Coal per steam H. P. per hour of main engines while engines were running	1.76 lbs.
Coal for plant per H. P. output per hour	2.02 lbs.
Coal for plant per kilowatt per hour	2.71 lbs.
Electrical efficiency	87.2

BOILER TESTS.

The summaries given represent the results of three tests made, not primarily with the aim of determining the evaporation per pound of coal, but to get, if possible, some idea of the ratio of heating surface to grate area, and also to find the loss of draught pressure and the leakage of air at different parts of the setting.

The boiler tested is set in battery with another boiler of the same size, there being a 20″ wall between the two.

The boiler is 60″ in diameter, 16 feet long, with eighty-four 3″ tubes 16 feet long. It rates at 100 horse power (A. S. M. E. rating). Built by the Roberts Iron Works Company, of Cambridgeport, Massachusetts.

The total heating surface, taking one half the shell and the inside surface of the tubes, is 1,113 square feet.

The grate area is 25.9 square feet. The grate is 24 inches from boiler.

The bridge wall is straight across the top, and 8 inches below the bottom of the boiler.

During the first test (Nos. 146–148) the boiler tested was run at a maximum rate, fires in the other boiler being banked.

During the second test (Nos. 149–151) 38 tubes were plugged, reducing the heating surface from 1,113 to 670.6 square feet. The boiler was run so as to keep the evaporation per square foot of heating surface the same as in the first test.

The same method was followed in the third test, 52 tubes being plugged and the heating surface reduced to 507.5 square feet.

During the second and third tests Boiler No. 4 was run at a moderate rate, and there may have been some heat carried to No. 5 Boiler through the middle wall of the setting. Before the test the brickwork of the setting was pointed up. The brickwork was not whitewashed. The tubes were plugged with iron caps at both ends.

Samples of gas and draught pressures were taken at different parts of the setting, porcelain tubes having been built into the setting for this purpose. These tubes were located over the grate, in the ash pit, over the bridge wall, halfway from bridge wall to the back of the boiler, at the back end of the boiler, and in the uptake.

The gases from both boilers were discharged into a wrought iron stack (unlined), 3 feet diameter and 100 feet tall. An iron ladder and four stagings were built on the wall of the building near the stack, and observations of temperature and draught pressure were taken at these four points in addition to the others.

These readings are quite interesting, as they give some idea of the loss of draught pressure with loss of temperature, and also the amount of cooling of the gases.

The accompanying photograph (Fig. 1), taken during the test, shows the ladder and the protection given the stack by surrounding buildings.

FIG. 1. THE SMOKE-STACK AND LANDINGS.

SUMMARY OF A 24-HOUR BOILER TEST.

Date, January 13, 1896, 8 A.M., to January 14, 8 A.M. Nos. 146–148.

Time.	PRESSURES.		TEMPERATURES. °C.					WEIGHTS.		Results of calorimeter experiments.	REMARKS.
	Barometer. (Lbs. per sq. in.)	Steam gauge.	Outside air.	Flue.	Feed before.	Feed after.	Temperature fire room.	Lbs. of water. (Boiler No. 5.)	Lbs. of fuel. (Boiler No. 5.)		
Jan. 13. 8 to 4.	14.74	63.5	1.4	199	8.2	27.6	....	35,582	4,640	.993	Ash and clinker. 410
Jan. 13. 4 to 12.	14.77	69.5	— .9	206	6.4	28.1	18.1	30,848	3,900	.994	566
Jan. 14. 12 to 8.	14.76	73.5	—3.4	218	7.8	35.7	24.2	28,423	3,768	.994	438
Total,		206.5	—2.9	623	22.4	91.4		94,853	12,308		1,414
Average,	14.76	68.8	—.97	208	7.5	30.5				.994	

		Boiler No. 5.
1.	Description of boiler: Horizontal multitubular.	
2.	Grate surface, No. 5, 60¾ in. by 61½ in. Area, feet	25.9
3.	Water-heating surface, feet	1,113.3
4.	Ratio of water-heating surface to grate surface	42.9
5.	Pounds coal fired, including coal equivalent of wood	12,308
6.	Unburned fuel	0
7.	Coal burned, including coal equivalent of wood	12,308
8.	Average coal burned for 15 minutes	128.21
9.	Total refuse from coal	1,414
10.	Total combustible	10,894
11.	Average combustible for 15 minutes	113.48
12.	Average pounds of air for — minutes	——
13.	Air per pound of coal	——
14.	Air per pound of combustible	——
15.	Quality of steam, saturated steam taken as unity	.994
16.	Total water pumped into boiler and apparently evaporated	94,853
17.	Water apparently evaporated per pound of coal	7.71
18.	Water actually evaporated, corrected for quality of steam	94,284
19.	Equivalent water evaporated into dry steam, from and at 212° F.	113,794
20.	Equivalent water evaporated into dry steam, from and at 212° F., per pound of coal	9.24
21.	Equivalent water evaporated into dry steam, from and at 212° F., per pound of combustible	10.44
22.	Coal burned per square foot of grate surface per hour	19.8
23.	Water evaporated, from and at 212° F., per square foot of heating surface per hour	4.26

ANALYSIS OF COAL.	ANALYSIS OF ASH.
C, 82.41%	C, 23.7%
H, 1.80%	H, 0.2%
H_2O, 1.87%	Ash, 75.0%
Ash, 9.46%	

Entire heating surface. No tubes plugged.

TEMPERATURE. °CENT.

Date, January 13–14, 1896. Nos. 146–148.

Time.	Flue.	STACK.				Time.	Flue.	Time.	Flue.
		1st landing.	2d landing.	3d landing.	4th landing.				
8.00	200	....	....	....	....	4.30	215	2.00	230
8.15	207	....	....	....	....	4.45	200	2.15	236
8.30	191	....	....	....	....	5.00	210	2.30	230
8.45	180	....	....	....	....	5.15	202	2.45	232
9.00	194	....	....	....	....	5.30	220	3.00	213
9.15	185	....	....	....	....	5.45	222	3.15	202
9.30	172	....	....	....	....	6.00	215	3.30	225
9.45	190	....	....	....	....	6.15	230	3.45	227
10.00	190	....	....	....	....	6.30	225	4.00	232
10.15	192	....	....	....	....	6.45	210	4.15	211
10.30	185	....	....	....	....	7.00	212	4.30	202
10.45	190	....	....	....	....	7.15	228	4.45	224
11.00	206	....	....	....	....	7.30	219	5.00	234
11.15	192	....	....	....	....	7.45	196	5.15	222
11.30	205	....	....	....	....	8.00	204	5.30	....
11.45	195	....	....	....	....	8.15	195	5.45	218
12.00	206	200	193	182	157	8.30	205	6.00	....
12.10	....	190	188	185	162	8.45	202	6.15	....
12.15	198	....	....	....	....	9.00	197	6.30	226
12.20	....	198	189	188	168	9.15	207	6.45	191
12.30	212	202	195	187	174	9.30	205	7.00	206
12.40	....	197	187	187	173	9.45	217	7.15	230
12.45	199	....	....	....	....	10.00	205	7.30	239
12.50	....	198	189	186	172	10.15	198	7.45	220
1.00	206	202	194	179	174	10.30	186	8.00	210
1.15	195	....	....	....	....	10.45	204	....	....
1.30	201	....	....	....	....	11.00	213	....	....
1.45	214	....	....	....	....	11.15	203	....	....
2.00	221	....	....	....	....	11.30	156	....	....
2.15	216	....	....	....	....	11.45	176	....	....
2.30	197	....	....	....	....	12.00	208	....	....
2.45	206	....	....	....	....	12.15	210	....	....
3.00	192	....	....	....	....	12.30	220	....	....
3.15	208	....	....	....	....	12.45	209	....	....
3.30	214	....	....	....	....	1.00	193	....	....
3.45	211	....	....	....	....	1.15	215	....	....
4.00	210	....	....	....	....	1.30	210	....	....
4.15	209	....	....	....	....	1.45	....	....	....

GAS ANALYSIS.

Date, January 13-14, 1896. Nos. 146-148.

Time.	Over Grate.				Over Bridge Wall.				Back of Boiler.				Flue.			
	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.
8.00	....	...	....	....	....	...	....	....	....	....	...	....	....	....	...	....
9.00	....	...	....	....	....	...	....	....	....	....	...	....	....	....	...	....
10.00	7.2	0.4	15.4	77.0	9.0	0.0	16.4	74.6	....	....	...	....	13.0	5.4	0.4	81.2
11.00	4.8	0.2	19.8	75.2	8.0	0.4	19.8	71.8	18.2	0.4	3.2	78.2	14.6	5.6	0.0	79.8
12.00	....	...	....	....	....	...	....	....	....	....	...	....	....	....	...	....
1.00	5.8	0.0	17.9	76.3	8.8	0.0	15.0	76.2	7.6	11.6	0.4	80.4	12.0	8.2	0.0	79.8
2.00	15.0	0.0	7.4	77.6	12.0	0.6	12.4	75.0	10.0	9.6	0.4	80.0	12.6	8.2	0.2	79.0
3.00	9.0	0.2	15.6	75.2	13.8	0.4	9.6	76.2	14.4	3.6	0.0	82.0	12.0	8.4	0.0	79.6
4.00	....	...	....	....	13.3	0.2	7.7	78.8	16.1	3.5	0.5	79.9	10.6	8.4	...	....
5.00	....	...	....	....	12.0	0.4	5.5	82.1	13.5	4.8	1.1	80.6	11.6	9.6	0.2	78.6
6.00	....	...	....	....	11.1	0.6	10.5	77.8	14.3	1.5	1.1	83.1	12.4	7.1	0.0	80.5
7.00	....	...	....	....	4.1	9.9	7.9	78.1	14.2	1.7	0.2	83.9	11.3	8.6	0.0	80.1
8.00	....	...	....	....	10.1	7.5	2.8	79.6	9.0	9.6	0.0	81.4	9.6	10.6	0.0	79.8
9.00	....	...	....	....	14.0	2.0	5.0	79.0	14.3	5.0	0.2	80.5	10.4	9.2	0 0	80.2
10.00	....	...	....	....	8.6	9.5	1.5	80.4	10.5	8.8	0.1	80.6	8.3	11.9	0.0	79.8
11.00	....	...	....	....	10.1	4.2	5.7	80.0	12.1	7.9	0.0	80.0	8.8	12.0	0.0	79.0
12.00	....	...	....	....	11.8	0.8	9.2	78.2	6.4	14.2	0.0	79.4	10.1	9.4	0.0	80.5
1.00	....	...	....	....	13.0	3.4	3.9	79.7	11.0	9.4	0.1	79.5	10.4	8.8	0.0	80.8
2.00	....	...	....	....	9.4	0.6	12.3	77.7	13.6	5.2	0.0	81.2	10.0	8.2	0.0	82.8
3.00	....	...	....	....	....	...	....	....	9.2	9.4	0.0	81.4	11.8	8.2	0.0	80.0
4.00	....	...	....	....	14.8	0.6	2.4	82.2	10.6	9.2	0.0	81.2	8.2	12.8	0.0	79.0
5.00	....	...	....	....	11.4	0.8	9.8	78.0	12.6	7.7	0.0	79.7	10.0	10.2	0.0	79.8
6.00	....	...	....	....	17.0	0.0	2.1	80.9	6.0	14.6	0.0	79.4	10.7	9.6	0.0	79.7
7.00	....	...	....	....	10.0	1.0	8.0	81.0	11.0	9.7	0.0	79.3	9.3	11.0	0.0	79.7
8.00	....	...	....	....	9.5	1.5	10.0	79.0	10.6	9.0	0.0	80.4	10.4	5.6	0.0	84.0

DRAUGHT PRESSURE. INCHES OF WATER.

Date, January 13-14, 1896. Nos. 146-148.

Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.	Stack.			
						1st landing.	2d landing.	3d landing.	4th landing.
8.00	.236	.382	.358	.284	.529	34 feet above grate. 24′ 3″ above center of flue.	51 feet above grate.	68 feet above grate.	85 feet above grate.
8.10					.515				
8.20					.542				
8.30	.204	.362	.352	.284	.538				
8.40					.503				
8.50					.511				
9.00	.232	.356	.390	.310	.522				
9.10					.520				
9.20					.491				
9.30	.256	.402	.424	.372	.518				
9.40					.528				
9.50					.544				
10.00	.252	.388	.434	.380	.527				
10.10					.526				
10.20					.552				
10.30	.164	.456	.446	.400	.526				
10.40					.535				
10.50					.558				
11.00	.170	.334	.330	.374	.439				
11.10					.543				
11.20					.565				
11.30	.218	.372	.374	.334	.542				
11.40					.563				
11.50					.562				
12.00	....	....	....	....	.546	.440		.168	.086
12.10					.554	.414	.332	.188	.116
12.20					.560	.428	.312	.168	.106
12.30	....	....	....	....	.572	.428	.312	.188	.104
12.40					.545	.434	.314	.186	.122
12.50					.556	.436	.328	.196	.088
1.00	....	....	....	....	.557	.436	.334	.216	.110

DRAUGHT PRESSURE. INCHES OF WATER. — *Continued.*

Date, January 13–14, 1896. Nos. 146–148.

Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.	Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.
1.10					.543	10.40					.527
1.20					....	10.50					.438
1.30	.240	.382	.410	.354	.560	11.00	.176	.336	....	.246	.510
1.40					.553	11.10					.463
1.50					.553	11.20					.365
2.00	.206	.322	.424	.288	.547	11.30	.186	.396	....	.326	.369
2.10					.569	11.40					.447
2.20					....	11.50					....
2.30	.170	.328	.372	.258	.443	12.00	.206	.356	....	.332	.688
2.40					.553	12.10					.558
2.50					....	12.20					.625
3.00	.228	.362	.364	.330	.546	12.30	.178	.398	....	.254	.523
3.10					.560	12.40					.495
3.20					.570	12.50					....
3.30	.258	.364	.424	.338	.560	1.00	.226	.388	....	.336	.638
3.40					.570	1.10					.428
3.50					.576	1.20					.420
4.00	.228	.348	.374	.244	.583	1.30	.114	.178	....	.146	....
4.10					.578	1.40					....
4.20					.588	1.50					.610
4.30	.236	.338	....	.278	.580	2.00	.248	.374	....	.342	.622
4.40					.588	2.10					.620
4.50					.588	2.20					.638
5.00	.240	.402	....	.348	.589	2.30	.190	.342	....	.300	.674
5.10					.581	2.40					.674
5.20					.604	2.50					....
5.30	.214	.322	....	.336	.577	3.00	.188	.344	....	.286	....
5.40					.589	3.10					.480
5.50					.589	3.20					.600
6.00	.228	.392	....	.366	.597	3.30	.308	.340	.284	.334	.616
6.10					.598	3.40					.618
6.20					.596	3.50					.614
6.30	.198	.260	....	.322	.597	4.00	.160	.238	.244	.202	.574
6.40					.457	4.10					.606
6.50					.599	4.20					.580
7.00	.214	.380	....	.354	.592	4.30	.168	.156	.234	.228	.618
7.10					.582	4.40					.516
7.20					.562	4.50					.570
7.30	.162	.314	....	.334	.605	5.00	.176	.314	.328	.262	.570
7.40					.573	5.10					.552
7.50					.585	5.20					.580
8.00	.220	.346	....	.356	.572	5.30	.176	.142	.232	.364	.594
8.10					.571	5.40					.608
8.20					.588	5.50					.616
8.30	.206	.368	....	.326	.590	6.00	.228	.324	.314	.294	.614
8.40					.560	6.10					.538
8.50					.562	6.20					....
9.00	.126	.394	....	.320	.513	6.30	.218	.136	.146	.206	.594
9.10					.516	6.40					....
9.20					.565	6.50					.564
9.30	.154	.366	....	.174	.405	7.00	.238	.340	.366	.340	.600
9.40					.408	7.10					.600
9.50					.464	7.20					.602
10.00	.168	.340	....	.206	.460	7.30	.236	.010	.380	.200	.604
10.10					.463	7.40					.632
10.20					.242	7.50					.724
10.30	.204	.342	....	.164	.241	8.00	.192	.018	.324	.186	....

SUMMARY OF A 22¾-HOUR BOILER TEST.

Date, January 14, 1896, 9.15 A.M., to January 15, 8 A.M. Nos. 149–151.

Time.	Pressures.		Temperatures. °C.					Weights.			Results of calorimeter experiments.	Remarks.
	Barometer. (Lbs. per sq. in.)	Steam gauge.	Outside air.	Flue.	Feed before.	Feed after.	Temperature boiler room.	Lbs. of water. (Boiler No. 5.)	Lbs. of fuel. (Boiler No. 5.)	Average lbs. of air. (Boiler No 5, for 15 minutes.)		Ashes and clinkers.
Jan. 14. 9.15 to 4.	14.76	72.9	4.5	193	6.8	27.0	26.0	17,791	2,300	1,594	.995	388
Jan. 14. 4 to 12.	14.80	74.3	— .4	208	7.4	30.4	27.3	23,905	3,150	1,396	.994	611
Jan. 15. 12 to 8.	14.85	76.8	—2.7	207	8.1	27.2	23.5	21,935	3,150	1,420	.993	438
Total,		224.0	1.4	608	22.3	84.6	76.8	63,631	8,600	4,410	.994	1,437
Average,	14.80	74.7	+.5	203	7.4	28.2	25.6			1,470		

		Boiler No. 5.
1.	Description of boiler: Horizontal multitubular.	
2.	Grate surface, No. 5, 60¾ in. by 61⅜ in. Area, feet	25.9
3.	Water-heating surface, feet	670.6
4.	Ratio of water-heating surface to grate surface	25.9
5.	Pounds coal fired, including coal equivalent of wood	8,600
6.	Unburned fuel	0
7.	Coal burned, including coal equivalent of wood	8,600
8.	Average coal burned for 15 minutes	94.51
9.	Total refuse from coal	1,437
10.	Total combustible	7,163
11.	Average combustible for 15 minutes	78.71
12.	Average pounds of air for 15 minutes	1,470
13.	Air per pound of coal	1,556
14.	Air per pound of combustible	18.7
15.	Quality of steam, saturated steam taken as unity	.994
16.	Total water pumped into boiler and apparently evaporated	63,631
17.	Water apparently evaporated per pound of coal	7.41
18.	Water actually evaporated, corrected for quality of steam	63,249
19.	Equivalent water evaporated intc dry steam, from and at 212° F.	76,484
20.	Equivalent water evaporated into dry steam, from and at 212° F., per pound of coal	8.89
21.	Equivalent water evaporated into dry steam, from and at 212° F., per pound of combustible	10.67
22.	Coal burned per square foot of grate surface per hour	14.6
23.	Water evaporated, from and at 212° F., per square foot of heating surface per hour	5.01

Analysis of Coal.		Analysis of Ash.	
C,	82.41 %	C,	23.7 %
H,	1.80 %	H,	0.2 %
H_2O,	1.87 %	Ash,	75 %
Ash,	9.46 %		

In this test 38 tubes were plugged, reducing the heating surface 442.7 square feet; the heating surface left being 670.6 square feet. This test was 22.75 hours long.

TEMPERATURE. °CENT.

Date, January 14–15, 1896. Nos. 149–151.

Time.	Flue.	STACK.				Time.	Flue.	Time.	Flue.
		1st landing.	2d landing.	3d landing.	4th landing.				
9.15	160	....	....	....	....	5.45	214	3.15	210
9.30	193	....	....	....	....	6.00	201	3.30	213
9.45	198	....	....	....	....	6.15	215	3.45	205
10.00	197	....	....	....	....	6.30	217	4.00	175
10.15	167	....	....	....	....	6.45	216	4.15	209
10.30	168	....	....	....	....	7.00	209	4.30	211
10.45	194	....	....	....	....	7.15	211	4.45	193
11.00	200	....	....	....	....	7.30	222	5.00	211
11.15	193	....	....	....	....	7.45	215	5.15	203
11.30	180	....	....	....	....	8.00	209	5.30	214
11.45	195	....	....	....	....	8.15	216	5.45	187
12.00	200	188	182	182	173	8.30	209	6.00	212
12.10	....	198	195	185	173	8.45	180	6.15	219
12.15	190	....	....	....	....	9.00	202	6.30	215
12.20	....	196	193	188	174	9.15	212	6.45	197
12.30	202	195	193	187	174	9.30	212	7.00	192
12.40	....	190	189	187	170	9.45	194	7.15	213
12.45	205	....	....	....	....	10.00	215	7.30	228
12.50	....	194	192	186	174	10.15	222	7.45	228
1.00	205	189	187	179	168	10.30	210	8.00	218
1.10	....	187	180	176	168	10.45	193	....	....
1.15	200	....	....	....	....	11.00	166	....	....
1.30	193	....	....	....	....	11.15	200	....	....
1.45	191	....	....	....	....	11.30	203	....	....
2.00	197	....	....	....	....	11.45	214	....	....
2.15	193	....	....	....	....	12.00	225	....	....
2.30	186	....	....	....	....	12.15	220	....	....
2.45	188	....	....	....	....	12.30	210	....	....
3.00	185	....	....	....	....	12.45	185	....	....
3.15	185	....	....	....	....	1.00	205	....	....
3.30	208	....	....	....	....	1.15	213	....	....
3.45	215	....	....	....	....	1.30	211	....	....
4.00	214	....	....	....	....	1.45	191	....	....
4.15	217	....	....	....	....	2.00	206	....	....
4.30	212	....	....	....	....	2.15	210	....	....
4.45	204	....	....	....	....	2.30	208	....	....
5.00	213	....	....	....	....	2.45	185	....	....
5.15	210	....	....	....	....	3.00	204	....	....
5.30	190	....	....	....	....	....	....	....	....

GAS ANALYSIS.

Date, January 14–15, 1896. Nos. 149–151.

Time.	Over Grate.				Over Bridge Wall.				Back of Boiler.				Flue.			
	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.
9.30	13.8	0.2	5.8	80.2	14.0	5.0	0.0	81.0	8.6	11.2	0.0	80.2	8.0	11.0	0.0	81.0
10.30	12.8	0.8	0 7	85 7	5.1	14.1	0.0	80.8	8.0	11.6	0.0	80.4	5.4	13.6	0.0	81.0
11.30	12.0	5.6	0.0	82.4	5.5	14.5	0.0	80.0	7.8	10.6	0.0	81.6	6.2	13.0	0.0	80.8
1.00	....	....	...	....	....	....	...	....	....	....	....	....	....	....	....	....
2.00	10.0	10.4	0.0	79.6	6.0	15.0	0.0	79.0	6.0	13.8	0.0	80.2	7.2	12.8	0.0	80.0
3.00	9.2	0.6	8.0	82.2	5.5	14.0	1.0	79.5	17.2	8.0	0.0	80.8	7.8	11.2	0.0	81.0
4.00	19.0	8.5	5.1	67.4	18.4	1.6	0 7	79.3	3.8	17.0	0.0	79.2	10.8	9.5	0.2	79.5
5.00	17.2	10.6	8.4	63.8	13.6	7.4	0.0	79.0	8.6	12.6	0.0	78.4	....	....	....	....
6.00	12.0	7.8	0.7	79.5	11.0	9.4	6.6	82.0	5.2	14.6	0.0	80.2	0.5	20.3	0.2	79.0
7.00	13.7	6.1	0.4	79.8	15.8	0.2	3.4	80.8	13.9	4.0	0.1	82.0	11.5	7.7	0.2	79.6
8.00	17.0	2.7	0.1	80.2	15.8	1.0	1.7	81.5	10.9	7.8	0.1	81.2	10.0	10.0	0.0	80.0
9.00	12.2	5.4	0.1	82.3	15.8	0.2	0.2	83.8	9.8	9.2	0.0	81.0	9.3	10.7	0.0	80.0
10.00	11.5	5.7	1.3	81.5	17.0	3.0	0.0	80.0	7.0	13.0	0.1	79.9	9.2	10.6	0.2	80.0
11.00	5.2	14.9	0.0	79.9	12.1	7.5	0.0	80.4	7.2	12.1	0.0	80.7	6.8	13.2	0.2	79.8
12.00	11.4	7.4	0.1	81.1	14.2	6.8	2.0	77.0	8.8	12.2	0.0	80.0	....	....	....	....
1.00	17.0	0.6	1.4	81.0	17.8	3.2	0.0	79.0	4.8	16.0	0.0	79.2	....	....	....	....
2.00	16.2	2.4	0.8	80.6	14.8	1.2	0.2	83.8	9.0	11.4	0.1	79.5	....	....	....	....
3.00	13 0	1.4	5.4	81.2	16.6	2.4	0.0	81.0	11.2	8.3	0.1	80.4	....	....	....	....
4.00	13.0	2.1	3.5	81.4	13.0	6.0	0.2	80.8	9.6	9.0	0.1	81.3	....	....	....	....
5.00	8.4	0.6	10.8	80.2	15.6	0.6	1.8	82.0	12.0	7.4	0.2	80.4	....	....	....	....
6.00	10.2	0.8	10.2	78.8	18.6	0.8	0.0	80.6	11.8	8.4	0.2	79.6	....	....	....	....
7.00	12.6	0.8	4.4	82.2	11.0	0.4	0.0	88.6	14.1	4.9	0.1	80.9	....	....	....	....
8.00	13.0	9.8	1.6	75.6	2.3	16.7	0.0	81.0	9.5	9.5	0.1	80.9	....	....	....	....

DRAUGHT PRESSURE. INCHES OF WATER.

Date, January 14–15, 1896. Nos. 149–151.

Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.	Stack.			
						1st landing.	2d landing.	3d landing.	4th landing.
9.20					.458				
9.30	.124	....	.100	.172	.498				
9.40					.480				
9.50					.472				
10.00	.120	....	.154	.148	.506				
10.10					.460				
10.20					....				
10.30	.136	....	.118	.206	.438				
10.40					.450				
10.50					.440				
11.00	.124	....	.216	.140	.478				
11.10					.468				
11.20					.438				
11.30	.116	.146	.134	.184	.440				
11.40					.409				
11.50					.470				
12.00	....	....	....	....	.480	.436	.330	.212	.210
12.10					.450	.426	.326	.218	.112
12.20					.498	.416	.318	.178	.084
12.30	....	....	....	....	.498	.426	.308	.200	.070
12.40					.476	.404	.300	.182	.130
12.50					.460	.432	.324	.192	.090
1.00	....	....	....	....	.492	.428	.314	.190	.104
1.10					.516	.414	.306	.206	.104

DRAUGHT PRESSURE. INCHES OF WATER. — *Continued.*

Date, January 14-15, 1896. Nos. 149-151.

Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.	Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.
1.20					.470	10.50					.416
1.30	.118	.178	.196	.166	.500	11.00	.140	.182	.208	.186	.501
1.40					.450	11.10					.525
1.50					.478	11.20					.567
2.00	.122	.190	.192	.142	.478	11.30	.176	.184	.068	.084	.533
2.10					.492	11.40					.547
2.20					.482	11.50					.565
2.30	.128	.192	.188	.176	.454	12.00	....	.222	.202	.186	.571
2.40					.460	12.10					.560
2.50					.488	12.20					.577
3.00	.124	.244	.204	.230	.508	12.30	....	.174	.196	.162	.556
3.10					.484	12.40					.536
3.20					.486	12.50					.464
3.30	.160	.230	.224	.224	.534	1.00	....	.218	.228	.144	.461
3.40					.474	1.10					.451
3.50					.504	1.20					.458
4.00	.140	.216	.216	.184	.532	1.30	....	.202	.196	.138	.453
4.10					.528	1.40					.457
4.20					.578	1.50					.453
4.30	.146	.232	.248	.196	.458	2.00	....	.226	.254	.186	.561
4.40					.506	2.10					.577
4.50					.564	2.20					.559
5.00	.054	.198	.218	.180	.492	2.30	....	.202	.226	.164	.568
5.10					.540	2.40					.531
5.20					.472	2.50					.525
5.30	.158	.230	.238	.190	.494	3.00	....	.240	.260	.234	.566
5.40					.572	3.10					.571
5.50					.560	3.20					.420
6.00	.168	.274	.270	.244	.500	3.30	....	.216	.224	.186	.545
6.10					.527	3.40					.536
6.20					.545	3.50					.497
6.30	.140	.214	.236	.200	.544	4.00	....	.264	.256	.214	.511
6.40					.544	4.10					.561
6.50					.507	4.20					.560
7.00	.114	.264	.294	.254	.555	4.30	....	.224	.224	.186	.563
7.10					.344	4.40					.572
7.20					.542	4.50					.546
7.30	.116	.198	.200	.168	.576	5.00	....	.254	.276	.200	.574
7.40					.470	5.10					.567
7.50					.454	5.20					.532
8.00	.152	.226	.252	.226	.555	5.30	....	.240	.242	.198	.574
8.10					.555	5.40					.550
8.20					.559	5.50					.540
8.30	.080	.124	.128	.100	.604	6.00	....	.256	.258	.214	.580
8.40					.567	6.10					.575
8.50					.490	6.20					.586
9.00	.164	.256	.260	.224	.556	6.30	....	.182	.200	.162	.496
9.10					.563	6.40					.585
9.20					.536	6.50					.530
9.30	.132	.198	.218	.174	.538	7.00	....	.230	.078	.170	.579
9.40					.553	7.10					.586
9.50					.325	7.20					.601
10.00	.148	.224	.236	.194	.514	7.30	....	.286	.252	.228	.619
10.10					.515	7.40					.615
10.20					.523	7.50					.611
10.30	.082	.118	.120	.086	.408	8.00	....	.380	.166	.254	.580
10.40					.370						

SUMMARY OF A 23¾-HOUR BOILER TEST.

Date, January 15, 1896, 8.30 A. M., to January 16, 8.15 A. M. Nos. 152–154.

Time.	PRESSURES.		TEMPERATURES. °C.					WEIGHTS.			Results of calorimeter experiments.	REMARKS.
	Barometer. (Lbs. per. sq. in.)	Steam gauge.	Outside air.	Flue.	Feed before.	Feed after.	Temperature fire room.	Lbs. of water. (Boiler No. 5.)	Lbs. of fuel. (Boiler No. 5.)	Average lbs. of air. (Boiler No. 5, for 15 minutes.)		
Jan. 15. 8.30 to 4.	14.88	74.6	4.5	189	6.8	30.1	21.6	18,851	1,960	1,157	.993	Ash and clinker. 253
Jan. 15. 4 to 12.	14.91	73.4	—.5	190	7.7	27.3	25.1	17,782	1,960	1,049	.994	387
Jan. 16. 12 to 8.15.	14.95	73.3	—4.2	192	8.2	30.5	23.6	17,971	2,310	1,263	.994	228
Total,		221.3	—.2	571	22.7	87.9	70.3	54,604	6,230	3,469		868
Average,	14.91	73.8	—.1	190	7.6	29.3	23.4			1,156	.994	

		Boiler No. 5.
1.	Description of boiler: Horizontal multitubular.	
2.	Grate suriace, No. 5, 60¾ in. by 61⅜ in. Area, feet	25.9
3.	Water-heating surface, feet	507.5
4.	Ratio of water-heating surface to grate surface	19.6
5.	Pounds coal fired, including coal equivalent of wood	6,230
6.	Unburned fuel	0
7.	Coal burned, including coal equivalent of wood	6,230
8.	Average coal burned for 15 minutes	65.58
9.	Total refuse from coal	868
10.	Total combustible	5,362
11.	Average combustible for 15 minutes	56.44
12.	Average pounds of air for 15 minutes	1,156
13.	Air per pound of coal	17.6
14.	Air per pound of combustible	20.4
15.	Quality of steam, saturated steam taken as unity	.994
16.	Total water pumped into boiler and apparently evaporated	54,604
17.	Water apparently evaporated per pound of coal	8.76
18.	Water actually evaporated, corrected for quality of steam	54,277
19.	Equivalent water evaporated into dry steam, from and at 212° F.	65,579
20.	Equivalent water evaporated into dry steam, from and at 212° F., per pound of coal	10.52
21.	Equivalent water evaporated into dry steam, from and at 212° F., per pound of combustible	12.23
22.	Coal burned per square foot of grate surface per hour	10.13
23.	Water evaporated, from and at 212° F., per square foot of heating surface per hour	5.44

ANALYSIS OF COAL.		ANALYSIS OF ASH.	
Carbon,	83.40%	Carbon,	20.9%
Hydrogen,	2.00%	Hydrogen,	0.4%
Moisture,	1.07%	Ash,	77.5%
Ash,	8.75%		

During this test 52 tubes were plugged, cutting down the heating surface 605.8 square feet, and leaving 507.5 square feet. This test was 23.75 hours long.

GAS ANALYSIS.

Date, January 15-16, 1896. Nos. 152-154.

Time.	OVER GRATE.				OVER BRIDGE WALL.				BACK OF BOILER.				FLUE.			
	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.
9.00	16.0	3.0	1.2	79.8	12.2	8.6	0.6	78.6	9.4	9.6	0.2	80.8	9.4	7.4	1.2	82.0
10.00	17.6	1.6	0.8	80.0	11.6	8.0	0.2	80.2	9.2	9.8	0.1	80.9	5.8	11.0	0.0	83.2
11.00	13.6	6.2	0.0	80.2	17.6	2.4	0.1	79.9	8.8	10.2	0.1	80.9	7.3	12.5	0.0	80.2
12.00	13.6	6.0	0.0	80.4	7.4	12.2	0.1	80.3	9.0	10.2	0.1	80.7	7.7	12.1	0.0	80.2
1.00	....	....	...	79.2	....	....	...	....	....	....	...	....	...	....	...	....
2.00	10.0	10.4	0.4	79.2	9.2	11.8	0.4	78.6	8.9	11.3	0.1	79.7	6.3	12.9	0.0	80.8
3.00	8 8	11.2	0.0	80.0	10.5	10.1	0.0	79.4	8.6	11.8	0.2	79.4	7.4	12.1	0.9	79.6
4.00	11.2	9.9	0.2	78.7	11.7	9.3	0.6	78.4	4.0	16.0	0.2	79.2	...	....	...	....
5.00	7.1	13.9	0.2	78.8	12.6	9 3	0.4	77.7	8.8	10.5	0.1	80.6	...	....	...	....
6.00	11.2	8.8	0.2	79.8	14.8	6.0	0.4	78.8	7.4	13.6	0.1	78.9	...	....	...	....
7.00	14.8	6.2	0.2	78.8	14.8	7.2	0.3	77.7	10.0	10.8	0.2	79.0	...	....	...	....
8.00	17.2	0.6	0.2	80.0	15.6	6.4	0.3	77.7	11.0	9.6	0.2	79.2	...	....	...	....
9.00	18.4	2.2	0.2	79.2	14.8	4.2	0.2	80.8	11.2	9.4	0.2	79.2	...	....	...	....
10.00	12.2	8.6	0.2	79.0	11.7	8.5	0.4	79.4	13.0	8.0	0.1	78.9	...	....	...	....
11.00	18.4	0.8	1.4	79.4	15.7	8.5	0.4	75.4	11.4	8.6	0.0	80.0	...	....	...	....
12.00	13.7	5.7	1.0	79.6	14.6	5.4	0.4	79.6	11.2	10.2	0.2	78.4	...	....	...	....
1.00	17.8	0.8	2.2	79.2	14.8	4.8	0.4	80.0	12.4	8.8	0.3	78.5	...	....	...	....
2.00	16.0	3.6	0.3	80.1	18.4	1.8	0.4	79.4	12.0	8.3	0.0	79.7	...	....	...	....
3.00	13.8	4.2	0.2	81.8	14.4	3.2	0.4	82.0	10.2	10.6	0.2	79.0	...	....	...	....
4.00	15.8	3.8	0.0	84.4	12.6	7.0	0.0	80.4	10.1	9.9	0.3	79.7	...	....	...	....
5.00	5.0	13.4	0.3	81.3	13.2	6.6	0.4	79.8	10.0	10.5	0.2	79.3	...	....	...	....
6.00	10.0	8.8	0.2	81.0	13.0	8.0	0.4	78.6	9.6	10.2	0.0	80.2	...	...	...	....
7.00	1.6	12.4	2.0	84.0	10.0	9.6	0.2	80.2	10.6	10.6	0.0	78.8	...	....	...	....
8.00	7.0	2.2	1.0	89.8	5.4	11.8	0.4	82.4	3.9	17.2	0.3	78.6	...	....	...	....

TEMPERATURE. °CENT.

Date, January 15–16, 1896. Nos. 152–154.

Time.	Flue.	STACK.				Time.	Flue.	Time.	Flue.
		1st landing.	2d landing.	3d landing.	4th landing.				
8.30	168	....	....	....	....	5.00	199	2.30	200
8.45	202	....	....	....	....	5.15	192	2.45	206
9.00	208	....	....	....	....	5.30	192	3.00	203
9.15	204	....	....	....	....	5.45	196	3.15	190
9.30	194	....	....	....	....	6.00	194	3.30	180
9.45	204	....	....	....	....	6.15	198	3.45	199
10.00	202	....	....	....	....	6.30	189	4.00	199
10.15	198	....	....	...	....	6.45	190	4.15	190
10.30	190	....	....	....	....	7.00	189	4.30	178
10.45	196	....	....	....	....	7.15	183	4.45	200
11.00	198	....	....	....	....	7.30	175	5.00	198
11.15	194	....	....	....	....	7.45	191	5.15	194
11.30	186	....	....	....	....	8.00	193	5.30	194
11.45	196	....	....	....	....	8.15	188	5.45	189
12.00	192	....	....	....	....	8.30	180	6.00	194
12.15	189	....	....	....	....	8.45	193	6.15	188
12.30	178	....	....	....	....	9.00	194	6.30	184
12.45	194	....	....	....	....	9.15	189	6.45	198
1.00	195	200	....	169	172	9.30	181	7.00	204
1.10	....	206	202	179	175	9.45	193	7.15	193
1.15	192	....	....	....	....	10.00	193	7.30	180
1.20	....	211	204	179	179	10.15	191	7.45	148
1.30	176	208	205	178	184	10.30	188	8.00	181
1.40	....	182	179	173	163	10.45	198	8.15	....
1.45	191	....	....	....	....	11.00	197	....	....
1.50	....	....	182	177	166	11.15	193	....	....
2.00	194	....	....	....	....	11.30	173	....	....
2.15	194	....	....	....	....	11.45	169	....	....
2.30	191	....	....	....	....	12.00	189	....	....
2.45	198	....	....	....	....	12.15	188	....	....
3.00	199	....	....	....	....	12.30	178	....	....
3.15	193	....	....	....	....	12.45	189	....	....
3.30	171	....	....	....	....	1.00	194	....	....
3.45	193	....	....	....	....	1.15	189	....	....
4.00	192	....	....	....	....	1.30	189	....	....
4.15	194	....	....	....	....	1.45	213	....	....
4.30	197	....	....	....	....	2.00	210	....	....
4.45	199	....	....	....	....	2.15	204	....	....

DRAUGHT PRESSURE. INCHES OF WATER.

Date, January 15–16, 1896. Nos. 152–154.

Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.	STACK.			
						1st landing.	2d landing.	3d landing.	4th landing.
8.30	....	.316	.190	.160	.197	....	....	....	....
8.40					.526				
8.50					.525				
9.00	.126	.174	.136	.102	.521	....	....	....	....
9.10					.643				
9.20					.458				
9.30	.090	.130	.174	.096	.528	....	....	....	....
9.40					.512				
9.50					.554				
10.00	.124	.166	.176	.112	.506	....	....	....	....
10.10					.529				
10.20					.516				
10.30	.114	.188	.170	.160	.511	....	....	....	....
10.40					.456				
10.50					.435				
11.00	.092	.128	.122	.106	.442	....	....	....	....
11.10					.435				
11.20					.497				
11.30	.150	.188	.200	.166	.514	....	....	....	....
11.40					.525				
11.50					.524				
12.00	.112	.124	.140	.110	.465	....	....	....	....
12.10					.500				
12.20					.505				
12.30	.114	.152	.162	.142	.521	....	....	....	....
12.40					.508				
12.50					.508				
1.00	....	....	....	....	.508	.404	.306	.240	.106
1.10					.483	.454	.334	.212	.130
1.20					.448	.450	.348	.222	.114
1.30	....	....	....	....	.435	.448	.322	.206	.108
1.40					.442	.426	.310	.230	.100
1.50					.436	.440	.300	.208	.120

DRAUGHT PRESSURE. INCHES OF WATER. — *Continued.*

Date, January 15–16, 1896. Nos. 152–154.

Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.	Time.	Over grate.	Bridge wall.	Under back of boiler.	Back of boiler.	Uptake.
2.00	.088	.124	.128	.100	.442	11.20					.445
2.10					.479	11.30	.106	....	.096	.014	.190
2.20					.482	11.40					.190
2.30	.114	.134	.182	.144	.479	11.50					.475
2.40					.482	12.00	.578	....	.136	....	.487
2.50					.479	12.10					.476
3.00	.096	.122	.150	.106	.487	12.20					.494
3.10					.475	12.30	.142	....	.178	.174	.495
3.20					.477	12.40					.528
3.30	.126	.150	.198	.128	....	12.50					.462
3.40					.532	1.00	.100	....	.184	....	.541
3.50					.523	1.10					.459
4.00	.074	....	.158	.116	.509	1.20					.487
4.10					.526	1.30	.146	....	.256	.188	.491
4.20					.482	1.40					.484
4.30	.094	....	.176	.116	.450	1.50					.584
4.40					.468	2.00	.100	....	.190	....	.594
4.50					.468	2.10					.592
5.00	.080	....	.142	.092	.476	2.20					.496
5.10					.454	2.30	.144	....	.232	.190	.588
5.20					.435	2.40					.593
5.30	.032	....	.196	.138	.481	2.50					.598
5.40					.410	3.00	.120	....	.190	....	.598
5.50					.416	3.10					.587
6.00	.592	....	.150	.104	.410	3.20					.514
6.10					.397	3.30	.164	....	.190	.160	.509
6.20					.395	3.40					.593
6.30	.672	....	.182	.138	.412	3.50					.535
6.40					.440	4.00	.102	....	.178	....	.533
6.50					.408	4.10					.509
7.00	.548	....	.136	.120	.401	4.20					.517
7.10					.417	4.30	.144	....	.206	.172	.536
7.20					.435	4.40					.537
7.30	.044	....	.192	.154	.385	4.50					.556
7.40					.432	5.00	.142	....	.176	....	.593
7.50					.420	5.10					.590
8.00	.474	....	.192	.100	.430	5.20					.519
8.10					.420	5.30	.122	....	.204	.174	.516
8.20					.420	5.40					.536
8.30	.664	....	.196	.148	.420	5.50					.599
8.40					.424	6.00	.122	....	.192	....	.595
8.50					.430	6.10					.590
9.00	.470	....	.166	.120	.430	6.20					.585
9.10					.430	6.30	.144	....	.260	.180	.592
9.20					.430	6.40					[illegible]
9.30	.072	....	.180	.150	.425	6.50					.594
9.40					.430	7.00	.120	....	.244	....	.593
9.50					.438	7.10					.590
10.00	.538	....	.170	.140	.434	7.20					.515
10.10					.430	7.30	.118	....	.144	1.26	.568
10 20					.430	7.40					....
10.30	.524	....	.188	.166	.455	7.50					.588
10.40					.448	8.00	.122	....	.200	....	.602
10.50					.440	8.10					.596
11.00	.522	....	.186	.148	.418	8.15					.560
11.10					.429						

PULSOMETER TESTS.

TESTS ON A NO. 4 PULSOMETER.

Made by the Pulsometer Steam Pump Company, of New York City.

Date.	Number of test.	Total lift. (Feet.)	Steam pressure at pulsometer. (Gauge.)	Steam used per hour. (Pounds.)	Water pumped per hour, including steam.	Temperature at suction. °C.	Temperature at discharge. °C.	Work done by pulsometer. (Foot-pounds.)	Total heat given up by steam. (B. T. U.)	Efficiency. (Per cent.)	Duty foot-pounds per 1,000,000. (B. T. U.)	Capacity. (Gallons per minute.)
1896.												
Feb. 13	1	18.50	17.3	189.0	18,360	22.6	28.3	337,800	209,100	.21	1,615,000	36.7
Feb. 13	2	18.78	25.7	193.6	20,850	28.2	33.4	389,900	219,200	.23	1,831,000	41.7
Feb. 14	3	17.30	34.7	192.4	18,030	27.7	33.6	310,300	219,100	.19	1,456,000	36.1
Feb. 14	4	18.16	37.5	192.0	17,500	32.3	37.9	316,200	211,400	.19	1,495,000	35.0
Feb. 17	5	22.22	11.5	196	11,890	25.3	34.5	262,300	214,800	.16	1,222,000	23.8
Feb. 17	6	20.39	31.5	197.4	8,176	31.9	43.5	164,700	214,800	.10	767,000	16.4
Feb. 18	7	22.90	27.4	197.2	10,170	28.9	39.0	231,000	215,700	.14	1,071,000	20.3
Feb. 18	8	25.15	29.5	191.5	14,700	30.9	37.8	368,270	210,100	.23	1,753,000	29.4
Feb. 20	9	23.48	28.9	195.2	14,610	28.7	36.7	341,300	214,500	.21	1,591,000	29.2
Feb. 21	10	24.15	27.7	195.3	13,340	31.0	39.0	320,300	213,700	.16	1,221,000	26.7
Feb. 21	11	24.50	19.0	195.7	14,530	32.8	39.8	354,400	213,100	.21	1,663,000	29.08
Feb. 24	12	25.32	37.8	196.6	17,530	26.0	32.9	442,200	218,100	.24	1,836,000	35.07
Feb. 24	13	21.02	33.9	197.1	9,906	36.0	46.2	206,650	215,200	.12	960,400	19.80
Feb. 25	14	24.54	33.4	197.2	16,690	31.4	37.0	408,000	217,000	.24	1,880,000	33.40
Feb. 27	15	27.61	61.2	371.0	37,040	38.3	45.7	1,019,000	405,400	.32	2,514,000	74.11
Feb. 28	16	25.32	58.4	412.1	31,230	45.0	53.4	786,600	442,800	.23	1,777,000	62.48
Mar. 2	17	28.14	41.3	474.6	37,900	35.8	44.2	1,062,000	517,200	.26	2,052,000	75.83
Mar. 3	18	23.22	50.3	497.4	31,110	39.4	49.9	713,400	538,500	.17	1,325,000	62.24
Mar. 5	19	27.28	49.5	480.6	35,950	34.5	44.0	985,500	525,400	.24	1,876,000	71.93
Mar. 5	20	27.41	42.5	419.4	35,660	35.7	43.5	972,900	458,000	.25	1,938,000	71.40
Mar. 6	21	29.61	54.1	421.5	39,680	35.8	43.2	1,171,000	462,000	.33	2,534,000	79.4
Mar. 6	22	24.86	50.8	476.6	33,020	42.1	51.4	815,800	514,800	.20	1,585,000	67.60
Mar. 10	23	29.42	50.1	468.2	40,150	27.2	35.5	1,176,000	519,300	.29	2,265,000	80.32
Mar. 10	24	25.93	26.3	246.0	31,110	41.5	47.4	803,900	265,800	.39	3,024,000	62.24
Mar. 12	25	27.51	30.2	304.5	37,760	24.5	31.9	1,035,000	338,200	.44	3,436,000	75.55
Mar. 12	26	25.92	29.2	324.0	33,790	32.6	38.9	872,200	354,800	.32	2,458,000	67.61
Mar. 13	27	29.46	26.8	285.7	39,660	25.3	29.9	1,130,000	316,500	.46	3,570,000	79.35
Mar. 13	28	28.68	30.2	293.9	38,700	32.7	38.0	1,106,000	322,400	.44	3,432,000	77.44
Mar. 16	29	29.23	28.5	303.6	38,360	25.1	29.6	1,118,000	337,600	.43	3,311,000	76.74
Mar. 16	30	32.17	28.1	332.5	45,320	19.4	24.3	1,454,000	372,400	.50	3,906,000	90.67
Mar. 17	31	31.46	30.5	299.5	43,680	23.3	28.5	1,371,000	333,700	.53	4,109,000	87.40
Mar. 17	32	29.64	30.1	313.5	40,020	32.3	37.5	1,183,000	344,200	.44	3,437,000	80.08
Mar. 19	33	29.05	24.5	253.6	39,550	23.4	28.0	1,146,000	282,200	.52	4,062,000	79.15
Mar. 19	34	30.23	30.9	336.1	41,410	29.2	34.3	1,248,000	371,100	.43	3,363,000	82.86
Mar. 20	35	30.36	31.5	330.0	41,660	31.0	36.4	1,137,000	363,400	.40	3,129,000	83.35
Mar. 20	36	27.08	31.7	300.2	34,200	36.8	42.4	821,000	327,200	.32	2,510,000	68.43
Mar. 23	37	31.25	31.2	305.8	44,210	22.8	27.9	1,378,000	341,300	.52	3,655,000	88.46
Mar. 23	38	28.63	28.6	330.6	36,550	36.2	41.9	1,043,000	360,400	.37	2,893,000	73.12
Mar. 24	39	29.66	21.9	258.8	40,960	28.2	32.8	1,212,000	284,700	.55	4,258,000	81.96
Mar. 24	40	28.64	29.9	319.1	36,910	37.3	42.9	1,054,000	347,300	.39	3,036,000	73.85
Mar. 26	41	31.56	28.6	340.1	43,350	22.2	27.4	1,364,000	379,600	.46	3,593,000	86.73
Mar. 27	42	29.56	28.8	315.8	41,160	28.1	32.9	1,212,000	349,300	.45	3,476,000	82.36
Mar. 27	43	28.41	26.1	310.4	37,230	34.9	40.1	1,054,000	339,000	.40	3,110,000	74.49

Water was drawn from a reservoir about 8 feet below the pump. The discharge pipe was 2½″ diameter.

TESTS ON THE FLOW OF STEAM.

EXPERIMENTS ON THE FLOW OF STEAM THROUGH AN ORIFICE ¼″ IN DIAMETER.

Date.	CALORIMETER TEST.				Boiler pressure.	Back pressure.	Orifice pressure.	Barometer pressure.	Weight of condensed steam.	Steam per hour by experiment.	By thermodynamic equation.	By Napier's formula.	Coefficient of flow from thermo equation.	Coefficient by Napier's equation.	Absolute back pressure. / Absolute boiler pressure.	Absolute orifice pressure. / Absolute boiler pressure.
	Boiler pressure.	Calorimeter pressure.	Calorimeter temperature.	Value of *x*.												
1895.																
Oct. 7	105.1	2.4	143.6	.995	95.6	51.7	55.1	14.5	268.4	268.4	278.8	277.9	.963	.966	.601	.632
Oct. 8	78.4	2.0	137.8	.998	87.5	46.0	50.3	14.5	252.7	252.7	258.2	257.6	.979	.981	.593	.635
Oct. 9	91.0	2.6	140.7	.998	87.5	51.0	53.4	14.7	249.3	249.3	254.0	252.3	.982	.988	.643	.666
Oct. 9	76.7	0.8	137.5	.998	89.2	56.2	57.8	14.7	246.2	246.2	253.6	249.4	.971	.987	.682	.698
Oct. 10	102.5	3.3	141.5	.994	100.5	52.5	57.3	14.9	280.1	280.1	289.9	291.3	.966	.962	.584	.626
Oct. 11	95.0	1.4	141.9	.997	93.1	46.8	52.2	14 9	268.3	268.3	264.2	272.6	1.016	.984	.571	.621
Oct. 14	103.4	2.1	142.1	.996	100.9	70.5	71.8	14.6	262.3	262.3	270.5	262.1	.970	1.007	.737	.748
Oct. 16	96.1	2.1	141.4	.996	95.9	50.4	54.8	14.7	273.4	273.4	278.2	280.6	.983	.974	.589	.628
Oct. 16	96.1	3.0	141.5	.997	95.7	53.5	56.8	14.7	268.0	268 0	276.1	276.5	.971	.969	.619	.649
Oct. 17	96.0	3.0	141.2	.996	95.6	55.8	57.5	14.6	134.6	269.2	274.5	272.7	.981	.987	.639	.646
Oct. 18	94.2	2.9	141.0	.996	94.0	68.4	68.7	14.8	235.6	235.6	248.5	238.2	.948	.989	.764	.767
Oct. 18	94.8	2.8	141.7	.998	95.6	42.1	52.7	14.8	272.1	272.1	279.4	278.6	.974	.977	.516	.612
Oct. 21	93.7	2.8	141.0	.996	93.0	49.7	53.4	14.7	265.5	265.5	269.5	272.1	.985	.976	.598	.632
Oct. 21	93.3	2.8	141.6	.997	93.0	45.0	51.6	14.8	267.3	217.3	270.8	272.0	.985	.983	.555	.616
Oct. 23	93.7	3.0	140.7	.996	93.5	55.2	57.2	14.7	195.2	260.1	267.8	265.6	.971	.979	.648	.667
Oct. 24	93.5	2.9	140.7	.996	93.9	56.8	58.7	14.9	255.4	255.4	268 1	265.8	.953	.961	.659	.676
Oct. 25	96.2	3.1	140.9	.995	93.1	64.4	64.5	14.6	243.2	243.2	256.0	245.2	.950	.992	.734	.735
Oct. 25	94.3	3.2	141.2	.996	94.1	62.0	62.8	14.5	248.0	248.0	260.7	255.4	.951	.971	.704	.712
Oct. 28	94.2	3.1	141.0	.996	93.7	56.3	58.3	14.6	264.0	264.0	266.1	265.3	.992	.995	.655	.673
Oct. 29	95.9	3.1	140.8	.995	95.7	65.8	66.7	14.8	249.5	249.5	260.2	253.1	.959	.986	.729	.737
Nov. 4	96.1	3.3	142.4	.996	96.9	39.9	52.9	15.0	273.4	273.4	282.1	282.6	.969	.967	.491	.607
Nov. 5	86.0	2.8	140.9	.998	95.7	47.0	53.5	15.0	271.3	271.3	275.8	279.3	.984	.971	.560	.619
Nov. 6	96.4	3.1	142.3	.997	96.4	48.4	54.1	15.0	283.3	274.2	281.4	281.2	.975	.975	.569	.621
Nov. 6	95.8	3.1	140.4	.995	97.1	72.3	72.6	14.9	238.8	238.8	256.3	239.6	.931	.996	.779	.781
Nov. 7	86.8	2.7	138.9	.997	96.6	66.4	67.5	14.8	246.8	246.8	261.5	255.1	.944	.967	.729	.739
Nov. 8	96.9	3.4	141.2	.995	96.7	66.4	67.3	14.8	249.4	249.4	262.0	254.5	.951	.980	.728	.736
Nov. 8	98.2	3.5	141.3	.995	97.1	69.4	69.8	14.8	242.5	242.5	258.6	243.1	.938	.998	.755	.756
Nov. 11	95.4	3.0	142.5	.997	96.1	51.7	55.3	15.0	270.1	270.1	277.9	280.3	.972	.963	.600	.633
Nov. 14	85.5	3.0	139.3	.996	86.4	50.2	51.8	14.9	244.3	244.3	252.7	250.2	.967	.976	.643	.658
Nov. 15	86.8	2.7	139.5	.997	85.5	51.4	52.9	14.6	237.0	237.0	247.0	244.5	.959	.970	.659	.674
Nov. 18	87.1	2.7	140.3	.997	85.7	46.8	49.8	14.7	237.1	244.4	252.1	252.0	.970	.970	.613	.628
Nov. 21	85.6	1.4	138.6	.997	95.8	54.5	55.3	14.7	236.6	236.6	245.6	239.8	.963	.987	.689	.697
Nov. 22	85.5	2.7	139.9	.997	85.2	40.5	46.7	15.0	248.4	248.4	253.3	251.9	.981	.986	.554	.616
Nov. 25	85.6	1.3	139.5	.997	85.2	43.8	47.7	14.9	236.7	236.7	252.7	252.9	.937	.936	.587	.625

For description of orifice, see Technology Quarterly, Vol. VIII, No. 1.

TESTS ON DAVIS PUMP.

Date.	Revolutions per minute of driving shaft.	Revolutions per minute of pump shaft.	Suction head in feet.	Discharge head in feet.	Velocity head in feet.	Total head in feet.	Power given to pump. (H. P.)	Work done by pump. (H. P.)	Efficiency. (Per cent.)	Capacity. (Gallons per minute.)	Vertical distance between gauges.
1895.											
Oct. 24	106.2	19.4	6.92	63.74	.11	71.83	1.59	1.09	68.2	59.8	1.06
Oct. 25	105.0	19.2	6.58	55.43	.11	63.18	1.45	.95	65.5	59.4	1.06
Oct. 25	105.8	19.4	6.80	57.97	.12	65.95	1.46	1.01	69.5	60.8	1.06
Oct. 28	104.5	19.1	7.03	66.05	.11	74.25	1.61	1.11	68.9	59.2	1.06
Oct. 28	103.8	19.00	6.69	67.28	.11	77.14	1.13	1.14	71.3	58.6	1.06
Oct. 30	101.4	18.57	7.14	76.21	.10	84.51	1.69	1.21	72.0	57.0	1.06
Oct. 31	100.4	18.38	7.14	82.91	.10	90.21	1.88	1.29	68.8	56.6	1.06
Nov. 4	100.9	.....	6.92	89.34	.10	97.92	2.00	1.41	71.0	57.3	1.06
Nov. 4	104.0	19.04	6.92	90.53	.10	98.61	2.06	1.48	72.1	59.5	1.06
Nov. 5	102.0	18.7	6.80	97.23	.10	105.19	2.09	1.53	73.2	57.5	1.06
Nov. 6	98.2	14.00	6.92	99.08	.09	107.15	2.05	1.50	73.1	55.4	1.06
Nov. 6	99.2	18.2	6.83	98.61	.09	106.59	2.03	1.48	72.9	55.0	1.06
Nov. 7	100.4	.....	7.26	104.39	.11	112.82	2.09	1.61	76.7	56.4	1.06
Nov. 8	101.3	18.5	7.37	125.09	.10	133.62	2.50	1.94	77.5	57.5	1.06
Nov. 14	103.7	19.0.	6.92	83.60	.10	91.68	1.74	1.34	77.6	58.3	1.06
Nov. 15	106.2	19.4	8.17	133.49	.10	142.82	3.05	2.12	69.4	58.8	1.06
Nov. 18	110.1	20.2	6.24	65.36	.11	72.77	1.58	1.14	72.7	62.3	1.06
Nov. 18	109.8	20.1	7.14	63.97	.11	72.28	1.57	1.14	72.8	62.7	1.06
Nov. 19	111.5	20.4	6.61	30.95	.11	38.73	.94	.62	65.6	63.3	1.06
Nov. 20	111.3	20.4	7.26	31.72	.11	79.35	.82	.62	76.0	62.8	1.06

TEST ON BELT MACHINE, USING 4″ DOUBLE LEATHER BELT.

Date.	Number of test.	Horse power.	Speed of east belt. (Feet per minute.)	Speed of west belt. (Feet per minute.)	Speed of circumference of southeast pulley.	Speed of circumference of northeast pulley.	Speed of circumference of southwest pulley.	Speed of circumference of northwest pulley.	Sum of tensions. (East belt.)	Difference of tensions. (East belt.)	Tension tight side. (East belt.)	Tension loose side. (East belt.)	Tension per inch of width, tight side. (East belt.)	Tension per inch of width, loose side. (East belt.)	Sum of tensions. (West belt.)	Difference of tensions. (West belt.)	Tension tight side. (West belt.)	Tension loose side. (West belt.)	Tension per inch of width, tight side. (West belt.)	Tension per inch of width, loose side. (West belt.)	Coefficient of friction. (East belt.)	Coefficient of friction. (West belt.)
Nov. 7	1	3.66	2,214	2,203	2,199	2,202	2,199	2,196	400	54.6	227.3	172.7	56.8	43.2	400	54.9	227.5	172.5	56.9	43.1	.087	.088
Nov. 7	2	5.36	2,203	2,191	2,189	2,192	2,189	2,185	405	80.3	242.6	162.4	48.5	40.6	405	80.7	242.8	162.2	48.5	40.5	.128	.128
Nov. 8	1	7.14	2,224	2,210	2,208	2,213	2,208	2,204	407	105.9	256.5	150.5	64.1	37.6	407	106.6	256.8	150.2	64.2	37.5	.170	.171
Nov. 8	2	8.71	2,186	2,170	2,169	2,175	2,169	2,163	411	131.6	271.3	139.7	67.8	34.9	411	132.5	271.8	139.2	67.9	34.8	.211	.213
Nov. 8	3	8.63	2,161	2,144	2,150	2,151	2,150	2,139	411	131.9	271.5	139.6	67.9	34.9	411	132.9	272.0	139.2	68.0	34.8	.212	.214
Nov. 8	4	6.98	2,174	2,157	2,158	2,163	2,158	2,153	407	105.9	256.5	150.6	64.1	37.6	407	106.8	256 9	150.1	64.2	37.5	.169	.171
Nov. 11	1	5.37	2,207	2,196	2,192	2,195	2,192	2,189	404	80.3	242.1	161.9	60.5	40.4	404	80.8	242.4	161.6	60.5	40.4	.128	.128
Nov. 11	2	3.69	2,229	2,220	2,215	2,218	2,215	2,213	400	54.6	227.3	172.7	56.8	43.1	400	54.8	227.4	172.6	56.8	43.1	.087	.088
Nov. 11	3	3.65	2,202	2,195	2,190	2,193	2,190	2,189	452	54.7	253.3	198.7	63.3	49.6	452	54.9	253.4	198.6	63.3	49.6	.077	.077
Nov. 11	4	3.65	2,201	2,196	2,191	2,195	2,191	2,190	452	54.7	253.3	198.7	63.3	49.6	452	54.9	253.4	198.6	63.3	49.6	.077	.077
Nov. 12	1	5.29	2,175	2,163	2,159	2,161	2,159	2,156	454	80.3	267.2	186.8	66.8	46.7	454	80.8	267.4	186.6	66 9	4.66	.114	.112
Nov. 12	2	6.96	2,167	2,154	2,152	2,155	2,152	2,147	455	106.0	280.5	174.5	70.1	43.6	455	106 6	280.8	174.2	70.2	43.5	.151	.152
Nov. 13	3	9.88	2,070	2,054	2,054	2,060	2,054	2,048	459	157.5	308.3	150.8	77.1	37.7	459	158.7	308.9	150.2	77.2	37.5	.227	.229
Nov. 13	4	8.49	2,121	2,107	2,105	2,112	2,105	2,100	457	132.0	294.5	162.5	73.6	40 6	457	132.9	295.0	162.6	73.7	40.6	.189	.190
Nov. 13	1	8.55	2,142	2,129	2,127	2,132	2,127	2,126	459	131.7	295.3	163.6	40.9	40.9	459	132.6	295.8	163.2	40.8	40.8	.185	.187
Nov. 13	2	10.21	2,136	2,124	2,121	2,128	2,121	2,120	464	157.7	310.8	153.1	38.3	38.2	464	158.6	311.3	152.7	38.2	38.1	.225	.226
Nov. 14	1	6.94	2,159	2,147	2,145	2,149	2,145	2,140	450	106.2	278.1	171.9	69.5	42.9	450	106.7	278.4	171.6	69.6	42.9	.153	.154
Nov. 14	2	6.91	2,151	2,137	2,137	2,140	2,137	2,131	453	106.1	279.5	173.5	69.9	43.3	453	106.8	279.9	173.1	70.0	43.2	.152	.153
Nov. 15	1	4.87	2,159	2,167	2,144	2,149	2,144	2,142	450	74.4	262.2	187.8	65.6	46.9	450	74.2	262.1	187.9	65.5	46.9	.106	.106
Nov. 15	2	3.21	2,156	2,167	2,164	2,168	2,164	2,161	450	49.1	249.5	200.5	62.4	50.1	450	48.8	249.4	200.6	62.4	50.1	.069	.069
Nov. 15	3	1.91	2,186	2,176	2,168	2,170	2,168	2,167	500	28.96	264.5	235.5	46.1	58.8	500	29.1	264.5	235.5	46.1	58.8	.038	.038
Nov. 18	1	3.68	2,228	2,219	2,215	2,216	2,215	2,212	500	54.5	277.2	227.7	69.3	55.6	500	54.7	277.4	222.6	69.3	55.6	.070	.070
Nov. 18	2	5.39	2,211	2,202	2,199	2,203	2,199	2,195	508	80.4	294.2	213.8	73.5	53.4	508	80.7	294.4	213.6	73.6	53.4	.101	.102
Nov. 18	3	6.90	2,151	2,136	2,134	2,139	2,134	2,131	510	105.9	307.9	202.1	77.0	50.5	510	106.6	300.3	201.7	77.0	50.4	.135	.136
Nov. 18	4	8.57	2,148	2,151	2,132	2,138	2,132	2,129	512	132.3	322.2	189.8	80.5	47.4	512	132.1	322.0	190.0	80.5	47.7	.168	.168
Nov. 19	1	8.46	2,119	2,106	2,105	2,110	2,105	2,099	510	131.8	320.9	189.1	80.2	47.2	510	132.1	321.3	188.7	80.3	47.1	.170	.169
Nov. 19	2	6.94	2,159	2,147	2,145	2,149	2,145	2,140	508	106.1	307.1	201.0	76.8	50.2	508	106.7	307.4	200.7	76.9	50.1	.135	.136
Nov. 20	2	3.62	2,165	2,157	2,172	2,176	2,172	2,168	503	55.2	279.1	223.9	69.8	55.9	503	55.4	279.2	223.8	69 8	55.9	.070	.071
Nov. 21	1	3.63	2,191	2,184	2,179	2,181	2,179	2,177	300	54.7	117.0	122.7	44.3	30.6	300	54.9	117.4	122.6	44.4	30.6	.117	.118
Nov. 22	1	1.95	2,237	2,232	2,236	2,227	2,226	2,225	600	28.8	314.4	285.6	78.6	71.4	600	28.9	314.4	285.6	78.6	71.4	.031	.031
Nov. 22	2	3.69	2,228	2,219	2,212	2,217	2,212	2,213	600	54.6	327.3	272.7	81.8	68.1	600	54.8	327.4	272.6	81.9	68.1	.058	.058
Nov. 22	3	5.30	2,179	2,168	2,166	2,169	2,166	2,163	600	77.2	338.6	261.4	84.7	65.3	600	77.6	338.8	261.2	84.7	65.3	.082	.083
Nov. 22	4	6.94	2,155	2,145	2,142	2,146	2,142	2,138	605	103.2	354.1	240.9	88.5	60.2	605	103.7	354.3	240.7	88.6	60.1	.122	.123
Nov. 25	1	8.42	2,106	2,094	2,092	2,099	2,092	2,088	600	131.9	366.0	234.1	91.5	58.5	600	132.6	366.3	233.7	91.6	58.4	.145	.143
Nov. 25	2	8.67	2,171	2,161	2,157	2,162	2,157	2,156	600	132.2	366.1	233.9	91.5	58.4	600	132.6	366.3	233.7	91.6	58.4	.143	.143
Nov. 25	3	6 88	2,178	2,169	2,170	2,171	2,170	2,164	600	104.3	352.2	247.8	88.1	61.9	600	105.0	352.5	247.5	88.1	61.8	.112	.113
Nov. 26	1	5.19	2,127	2,117	2,114	2,118	2,114	2,111	600	77.5	338.7	261.3	84.7	65.3	600	77.8	338.9	261.1	84.7	65.2	.083	.085
Nov. 26	2	3.61	2,184	2,175	2,170	2,173	2,170	2,168	600	51.6	325.8	274.2	81.5	68.5	600	51.8	325.9	274.1	81.5	68.5	.055	.053
Nov. 27	1	1.92	2,196	2,191	2,185	2,187	2,185	2,184	650	28.5	339.2	310.8	84.9	77.7	650	28.6	339.3	310.7	84.9	77.6	.028	.028
Nov. 27	2	3.78	2,187	2,182	2,177	2,179	2,177	2,175	650	57.1	353.5	296.5	88.4	74.1	650	57.2	353.6	296.4	88.4	74.1	.054	.054
Nov. 27	3	5.31	2,180	2,171	2,167	2,171	2,167	2,165	650	80.5	365.2	284.7	91.3	71.1	650	80.8	365.4	284.6	91.3	71.1	.079	.079

A brief description of this belt machine was given in Technology Quarterly, Vol. VIII, No. 1.

ENGINE TESTS.

TESTS ON THE TRIPLE EXPANSION ENGINE, 9″-16″-24″ × 30″, RUN AS A COMPOUND.

Horse power.	Steam per H. P. per hour.	Steam through cylinders per hour.	WATER BY JACKETS PER HOUR.		Revolutions per minute.	Boiler pressure. (Gauge.)	Vacuum in condenser. (Inches mercury.)	Barometer.
			Intermediate pressure cylinder.	Low pressure cylinder.				
1	2	3	4	5	6	7	8	9
52.0	22.67	......	....	....	83.02	43.5	27.01	30.5
54.67	.....	809.5	....	....	83.38	47.5	26.3	29.87
77.02	.....	1,658.0	....	....	81.05	44.0	25.25	29.36
77.50	.....	1,257.5	....	....	80.73	44.07	25.4	30.20
72.0	21.54	1,549.0	....	....	81.83	44.7	25.8	29.9
78.8	20.96	1,648.5	....	....	81.25	44.1	26.17	30.1
83.01	.....	1,773.0	....	....	80.83	49.0	25.3	29.91
84.18	.....	1,807.0	....	....	80.60	47.1	25.3	29.60
90.1	21.33	1,922.0	....	....	80.23	44.3	25.16	30.32
91.92	21.23	1,949.0	....	....	80.0	43.9	25.2	29.7
92.9	21.29	1,976.5	....	....	80.15	43.8	25.4	29.98
59.46	21.96	1,196.0	....	109.5	85.72	50.5	25.3	29.56
66.32	21.28	1,304.0	....	107.25	82.73	49.0	26.2	29.65
71.18	20.29	1,321.5	....	122.42	82.50	49.8	26.0	29.70
72.47	20.97	1,389.0	....	131.1	82.30	48.4	25.2	29.50
76.39	20.42	1,408.0	....	151.6	82.03	48.4	26.64	30.04
77.16	20.65	1,456.5	....	136.7	82.10	48.4	25.8	30.03
78.14	20.41	1,455.5	....	139.71	81.95	51.3	25.7	29.90
79.04	20.42	1,481.5	....	132.2	81.78	48.5	25.7	29.84
80.30	20.14	......	....	104.1	81.60	47.5	25.5	29.80
85.27	19.95	1,589.5	....	111.97	81.22	48.2	25.8	29.71
94.69	19.72	1,729.5	....	137.75	80.90	48.0	25.7	30.38
95.05	19.35	1,702.5	....	126.6	80.92	47.5	25.6	29.50
103.03	20.13	1,962.0	....	112.3	82.0	44.3	24.3	29.35
107.93	19.88	2,027.0	....	188.9	82.28	48.9	24.2	29.8
62.82	19.39	1,072.5	59.7	86.2	83.07	48.0	26.1	30.48
67.43	19.78	1,179.5	57.05	97.29	85.27	50.63	24.6	29.40
80.30	18.70	1,352.5	149.1	149.1	81.85	48.3	25.4	29.76
87.68	19.07	1,520.5	50.99	100.74	81.23	47.5	25.6	29.80
90.47	18.35	1,504.5	53.4	102.0	81.05	47.5	25.8	29.82
94.39	18.40	1,582.0	53.0	101.3	80.93	47.7	25.7	29.48

TESTS ON THE TRIPLE EXPANSION ENGINE, 9″-16″-24″ × 30″, RUN AS A COMPOUND. — *Continued.*

Intermediate Cylinder.									
Initial pressure.	Per cent. cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in the cylinder at cut-off.	Per cent. of steam in the cylinder at release.	M. E. P. crank.	M. E. P. head.	Horse power.
10	11	12	13	14	15	16	17	18	19
40.0	7.4	37.2	4.3	−4.4	71.56	85.75	13.59	12.21	32.4
47.0	7.6	41.7	−3.3	−2.3	59.89	79.25	11.87	12.15	30.25
26.7	21.1	38.9	2.7	2.8	70.70	82.27	15.96	17.49	40.98
46.9	21.0	40.5	2.7	2.8	71.93	83.16	16.32	18.18	42.10
41.3	15.7	37.0	0.2	−1.2	63.26	80.12	17.57	17.7	43.6
40.3	20.2	36.8	0.6	0.5	69.40	79.46	19.42	19.18	47.4
47.3	23.3	40.0	4.1	3.5	72.41	84.27	16.99	18.67	43.63
46.9	24.5	42.1	4.6	5.8	76.52	83.67	17.62	18.88	44.49
41.9	30.1	36.4	4.6	4.6	76.0	82.12	19.0	19.8	47.0
40.4	27.9	37.7	4.0	1.7	74.36	79.20	23.37	22.6	55.6
41.0	29.0	37.1	4.6	1.4	74.0	81.0	23.48	22.85	56.1
46.5	8.7	34.0	−2.1	0.7	56.11	86.99	9.19	9.60	24.34
45.9	10.7	41.2	−0.1	1.2	62.79	89.82	10.81	11.46	27.85
47.1	11.7	39.9	−8.0	1.0	63.39	85.76	12.29	12.63	31.07
46.2	12.8	38.8	−0.8	2.8	62.25	80.57	13.39	13.75	33.76
47.3	13.6	43.0	0.3	3.1	67.43	85.08	12.49	13.35	32.04
46.0	13.5	41.3	0.1	1.3	64.38	82.63	13.52	14.80	35.15
46.2	14.5	39.6	0.6	3.3	64.04	84.15	13.36	13.88	33.74
45.9	15.5	40.0	1.4	3.8	65.88	86.51	12.89	13.47	32.58
45.5	16.5	38.2	1.1	2.5	65.56	83.62	14.04	15.74	36.74
47.3	17.2	43.5	1.5	3.0	59.68	81.49	15.02	16.70	38.95
46.9	21.6	42.4	3.3	4.0	73.22	84.06	16.95	18.35	43.17
46.0	22.5	41.0	2.9	4.6	73.73	80.79	16.50	18.12	42.71
43.1	33.0	36.5	7.2	8.6	78.10	87.0	18.71	18.52	46.14
47.2	31.2	40.5	5.7	7.8	79.35	80.62	19.78	17.98	46.92
47.6	7.8	44.2	−3.0	−1.8	69.87	91.65	11.86	12.54	30.67
47.8	10.1	40.9	−1.9	−0.9	66.74	89.06	12.60	13.66	33.84
47.8	15.2	42.9	0.6	2.5	73.50	88.83	14.57	16.35	38.26
46.7	19.7	41.9	2.2	2.0	77.58	88.48	16.79	18.62	43.48
47.3	19.8	41.3	0.9	1.7	77.60	82.68	16.81	18.42	43.16
47.5	21.5	42.4	3.1	5.2	78.0	86.52	16.80	18.21	42.31

Intermediate leading the low by 120 degrees.

TESTS ON THE TRIPLE EXPANSION ENGINE, 9″-16″-24″ × 30″, RUN AS A COMPOUND. — *Concluded.*

Low Pressure Cylinder.											
Initial pressure.	Per cent. cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in the cylinder at cut-off.	Per cent of steam in the cylinder at release.	M. E. P. crank.	M. E. P. head.	Horse power.	B. T. U. per H. P. per minute. (Actual.)	B. T. U. per H. P. per minute. (Reduced to 26″ vacuum.)
20	21	22	23	24	25	26	27	28	29	30	31
—7.1	40.5.	—8.15	—11.3	—12.7	62.93	69.13	3.26	3.62	19.70	409.5	429.9
—3.1	....	—6.1	—11.0	.....	55.98	66.50	4.28	4.26	24.42	399.8	413.2
1.6	....	—2.9	— 9.9	.....	54.03	58.85	6.44	6.51	36.04	386.9	386.9
1.8	....	—3.0	— 9.5	.....	52.85	67.52	6.37	6.41	35.40	383.6	377.1
4.1	43.0	—5.4	— 9.8	—11.7	62.0	69.50	4.78	5.31	28.40	382.8	382.8
—3.4	45.5	—5.6	— 9.18	—11.5	63.77	67.70	5.46	5.79	31.40	373.2	375.0
2.8	....	2.3	9.3	11.6	54.61	62.86	7.09	7.11	39.38	377.0	372.8
3.7	....	—1.0	— 9.2	.....	54.36	63.08	7.17	7.18	39.69	381.6	379.7
1.7	36.5	—1.0	9.1	10.9	63.38	66.54	7.73	7.91	43.10	376.8	370.6
—1.8	50.0	—4.1	— 8.3	11.0	61.27	68.19	—6.47	6.77	36.30	376.0	368.0
2.0	50.0	—3.6	— 8.2	11.0	64.43	65.65	6.64	6.72	36.80	377.5	372.1
1.0	....	—4.9	10.16	11.6	78.75	76.69	5.91	6.03	35.12	385.4	382.3
0.12	....	—2.5	—10.2	.....	75.79	75.29	6.57	6.98	38.47	377.7	384.4
—0.19	....	—3.5	10.0	.....	79.97	76.49	6.94	7.23	40.11	358.0	362.2
—0.10	....	—3.4	— 9.0	.....	84.64	85.55	6.87	6.84	38.71	367.6	365.4
1.67	....	—2.6	—10.1	.....	79 61	73.39	7.84	7.92	44.35	360.3	366.1
—0.5	....	—3.0	—10.0	.....	81.45	70.90	7.31	7.60	42.01	362.7	362.7
1.62	....	—2.2	— 9.9	.....	81.05	72.48	7.81	7.98	44.40	358.3	356.2
2.99	....	—1.9	— 9.5	.....	79.63	76.74	8.21	8.35	46.46	358.4	356.4
1.4	....	—2.9	— 9.5	.....	74.70	73.76	7.64	7.92	43.56	354.5	352.6
2.01	....	—2.0	— 9.3	.....	74.39	72.56	7.93	8.69	46.33	352.5	354.1
2.8	....	—1.0	— 8.8	.....	80.42	75.86	9.04	9.52	51.52	345.7	341.1
3.3	....	+0.6	— 8.6	.....	80.56	75.16	9.36	9.62	52.70	339.6	340.9
5.4	....	+1.1	— 7.7	.....	77.61	74.31	9.93	10.27	56.89	352.7	345.7
6.1	....	—1.7	— 7.4	.....	77.59	79.17	10.89	10.72	61.01	348.5	342.0
—2.3	....	—5.1	—11.0	....	89.09	81.73	5.61	5.67	32.16	338.0	332.9
—1.7	....	—4.5	—10.2	.....	86.19	79.90	5.52	5.96	33.59	344.6	337.1
0.9	....	—3.3	—10.0	.....	82.82	73.90	7.49	7.48	42.04	326.6	325.6
1.3	....	—2.4	— 9.2	.....	77.42	76.46	7.89	7.97	44.20	333.9	333.9
1.8	....	—2.0	— 9.3	.....	85.25	76.31	8.34	8.67	47.31	321.9	323.2
3.5	....	—0.6	— 9.6	.....	83.54	67.70	9.25	9.51	52.08	324.9	328.7

TESTS ON THE TRIPLE EXPANSION ENGINE, 9″-16″-24″ × 30″.

Horse Power. 1	Steam per H. P. per hour. 2	Steam through cylinders per hour. 3	Water by Jackets per Hour.			Revolutions per minute. 7	Boiler pressure. (Gauge.) 8	Vacuum in condenser. (Inches mercury.) 9	Barometer. 10
			High pressure cylinder. 4	Intermediate pressure cylinder. 5	Low pressure cylinder. 6				
53.21	17.28	919	....	....	....	85.60	152.8	26.1	29.7
55.73	16.86	931	....	....	....	85.62	153.3	26.1	....
60.6	16.19	981	....	....	....	85.60	152.1	26.1	29.9
69.8	15.80	....	....	....	....	81.66	146.3	19.8	29.7
74.9	15.39	1,148	....	....	....	84.22	152.8	25.9	29.8
85.8	15.12	1,298	....	....	....	83.03	152.0	26.3	....
86.9	15.39	1,338	....	....	....	82 92	152.4	26.09	30.15
87.8	15.26	1,339	....	....	....	82.55	153.0	26.02	30.0
91.1	15.47	1,409	....	....	....	83.32	152.0	25.70	....
99.9	15.54	1,552	....	....	....	82.67	151.9	25.6	30.0
100.5	15.16	1,525	....	....	....	81.78	152.0	25.7	....
102.4	14.95	1,531	....	....	....	82.92	152.5	26.0	29.9
106.0	15.24	1,631	....	....	....	81.52	151.5	26.1	29.9
108.2	14.91	1,613	....	....	....	81.57	152.0	26.0	....
111.2	14.33	1,592	....	....	....	81.40	152 0	26.04	30.1
112.2	15.16	1,693	....	....	....	81.50	151.9	25.9	30.26

HIGH PRESSURE CYLINDER.

Initial pressure. 11	Per cent. cut-off. 12	Pressure at cut-off. 13	Pressure at release. 14	Pressure at compression. 15	Per cent. of steam in the cylinder at cut-off. 16	Per cent. of steam in the cylinder at release. 17	M. E. P. crank. 18	M. E. P. head. 19	Horse power. 20
148.3	8.4	142.9	14.6	15.7	65.0	82.5	38.6	32.7	28.4
148.4	8.3	140.7	12.4	11.8	64.0	77.4	39.3	36.2	30.1
148.0	10.6	141.1	16.2	16.6	68.3	81.4	41.3	38 1	29.6
142.7	14.6	139.8	20.6	18.6	68.9	78.5	46.4	46.8	35.7
149.5	15.8	144.5	24.0	26.4	72.6	83.4	45.7	46.2	36.1
147.4	21.3	137.4	31.0	33.0	74.6	85.0	51.4	46.4	37.8
146.9	21.2	139.7	29.8	29.2	73.8	82.3	54.6	50.3	40.6
148.3	21.0	140.7	30.0	28.4	74.1	82.5	58.8	50.7	42.2
147.6	24.1	142.9	35.8	39.6	76.7	85 8	49.6	53.5	40.2
147.4	29.5	139.5	41.5	47.0	78.5	85.3	49.4	52.0	39.1
146.5	29.1	138.9	40.2	44.2	79.1	85.0	53.8	53.1	40.8
148.5	28.7	142.1	41.5	43.5	80.0	87.0	52 9	57.1	42.6
148.4	30.7	143.1	44.5	47.6	79.4	86.2	57.8	52.3	34.4
147.0	31.8	141.2	44.4	45.1	81 3	86.7	59.7	55.4	43 9
148 0	35.6	137.9	48.9	52.9	82.9	86.2	54.1	54.1	41.8
147.5	33.8	142.1	47.2	51.2	80 8	85.8	56.0	53.9	41.9

Cranks set 120° apart, high leading.

A description of the engine, together with quite an extended series of tests, can be found in Technology Quarterly, Vol. V, No. 3.

TESTS ON THE TRIPLE EXPANSION ENGINE, 9″-16″-24″ × 30″.—*Continued.*

Intermediate Cylinder.									
Initial pressure.	Per cent. cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in the cylinder at cut-off.	Per cent. of steam in the cylinder at release.	M. E. P. crank.	M. E. P. head.	Horse power.
21	22	23	24	25	26	27	28	29	30
12.5	15.5	7.4	—7.4	—5.9	48.8	71.40	5.46	5.27	13.9
9.1	22.5	4.9	—6.2	—5.1	54.6	83.96	5.61	5.20	14.0
13.7	17.5	9.4	—6.3	—5.2	53.1	75.31	6.42	5.98	16.0
15.7	25.3	10.0	5.1	3.5	59.1	74.86	7.89	8.42	20.1
22.5	16.5	16.4	—4.7	—2.0	.....	.....	7.56	8.86	20.9
29.5	17.7	24.8	—2.1	—0.08	61.83	81.12	9.74	10.55	25.7
26.9	21.5	20.0	—1.9	—1.1	58.60	81.49	8.89	9.99	23.7
24.5	22.5	18.5	—2.0	—0.5	59.69	80.80	9.22	9.18	23.0
33.3	18.0	26.8	—1.9	1.6	60.72	77.61	10.11	11.79	27.6
42.1	18.0	34.0	1.4	5.4	62.57	85.72	11.28	12.64	30.0
39.7	20.2	52.15	0.8	5.10	70.24	82.95	11.68	13.65	31.3
37.7	19.5	29.7	—0.3	3.2	62.44	79 10	11.62	13.29	31.2
42.5	19.5	36.1	1.1	4.6	65.60	79.85	14.15	13.77	34.4
40.0	21.5	31.3	0.8	4.0	64.64	80.14	13.79	13.60	33.6
47.2	18.3	40.3	1.7	4.5	65.30	80.46	14.8	14.6	36.5
47.1	20.5	38.0	2.7	0.9	66.91	84.43	14.0	14.10	36.0

Low Pressure Cylinder.										B. T. U. per H. P. per minute. (Actual.)	B. T. U. per H. P. per minute. (Reduced to 26″ vacuum.)
Initial pressure.	Per cent. cut-off.	Pressure at cut-off.	Pressure at release.	tom-pression.	Per cent. of steam in the cylinder at cut-off.	Per cent. of steam in the cylinder at release.	M. E. P. crank.	M. E. P. head.	Horse power.		
31	32	33	34	35	36	37	38	39	40	41	42
—7.9	26.0	—9 4	—11.7	—12.0	43 5	71.8	1.84	1.88	10.9	317.7	318.0
—6.9	24.5	—8.6	—11.7	—11.8	45.0	74.2	2.12	1.84	11.6	306.5	308.2
—7.2	24.5	—8.1	—11.2	—11.8	47.2	77.5	2.25	2.19	13.0	295.7	296.7
—5.0	48.9	—6 5	— 9.7	— 9.1	75.7	75.8	2.7	2.32	14.9	278.0	231.4
—5.2	25.9	—7.6	—11.3	—11.6	46.3	64.2	3.03	3.19	18.0	287.1	286.0
—2.4	18.5	—4.9	—11.3	—12.3	43.0	58.6	3.72	4.08	22 3	276.1	277.6
—1.7	20.0	—5.0	—11.0	—11.8	44.1	61.3	3.86	4.11	22.6	280.6	280.8
—2.2	21.5	—5.4	—10.8	—11.8	44.0	64.4	3.91	4.07	22.6	284.1	284.1
—1.8	22.0	—4 3	—10.5	—11.6	49.5	67.4	4.10	4.05	23.3	280.5	278.3
2.3	19.0	—1.9	—10.2	—11.6	48 1	63.7	5.35	5.5	30.8	283.0	280.3
1.5	18.0	—2.2	—10.2	—11.7	46.9	64.4	5.02	5.14	28.5	275.3	273.4
—0 2	21.0	—3.3	—10.9	—11.9	46.7	55.6	5.08	5.27	28.6	271.7	271.7
1.6	21.5	—2.1	—10.6	—11.4	40.3	58.4	5.57	5.57	29.7	278.1	277.6
1.3	22.0	—2.1	—10.3	—11.5	49.5	60.6	5.51	5.43	30.7	271.2	271.2
1.7	21.5	—0.8	— 9.7	—11.2	51.6	57.1	6.04	5.74	32.9	274.0	274.0
2.8	20.5	—0.3	— 9.6	—11.6	44.1	67.7	6.09	6.15	34.3	274.6	273.9

TESTS ON A HANCOCK INSPIRATOR.

Since the time of the tests that were quoted in the *Technology Quarterly*, Vol. VIII, Nos. 1 and 3, new apparatus for testing injectors has been supplied to the laboratories. The injectors are located on the second floor, and draw water from a 6-inch standpipe that runs through the first floor to the basement of the building, giving a lift of from 0 to 25 feet. The water admission to the standpipe is controlled by a balanced valve placed in the supply pipe, this valve being actuated, through a delicate mechanism, by a float in the standpipe itself. The feed supply is taken from the city main until the beginning of the test, when it is drawn from a tank of sufficient capacity for the whole run. This tank is placed on scales, and its weight is taken before and after the test. The delivery water is weighed in barrels. Arrangement has been made for getting an accurate start and finish of both the feed and the delivery. The delivery pressure is kept constant by a back pressure valve placed in the delivery pipe. This valve is connected with the steam pipe, and the delivery pressure is controlled by the working steam pressure. The difference in the weight of the delivery and the feed water is taken as the amount of steam used.

TESTS ON HANCOCK INSPIRATOR NO. 4, C.

Number of test.	Duration. (Minutes.)	Steam pressure.	Delivery pressure.	Barometer.	Lift. (Feet.)	Suction temperature. °F.	Delivery temperature. °F.	Water supplied. (Lbs. per hour.)	Water delivered. (Lbs. per hour.)	Steam used. (Lbs. per hour.)	Water delivered. (Per lb. of steam used.)	Thermal efficiency. (As pump and heater combined.)	Delivery.	Delivery capacity. (Gals. per hour.)
52	30	37.7	49.8	14.6	4.01	87.3	146.8	4,950	5,259	309	17.0	91.8	Max.	642
53	30	39.8	52.9	14.7	3.99	46.9	112.1	3,824	4,079	255	16.0	90.6	Min.	493
57	30	42.7	56.6	14.7	4.00	49.3	113.5	5,326	5,659	333	17.0	95.2	Max.	685
58	30	42.8	58.2	14.7	4.00	46.2	110.3	5,306	5,653	347	16.3	90.5	Max.	684
59	30	43.2	58.4	14.7	4.00	61.3	124.5	5,367	5,691	324	17.6	98.3	Max.	691
61	30	43.4	59.1	14.6	3.99	66.7	131.0	5,282	5,638	356	15.8	90.0	Max.	685
63	30	43.5	56.0	15.0	4.02	72.7	144.3	3,559	3,820	261	14.6	93.4	Min.	466
64	30	43.5	54.2	14.9	4.00	82.2	154.8	3,436	3,693	257	14.4	94.0	Min.	452
65	30	43.5	59.0	14.5	4.02	70.0	133.7	5,194	5,522	328	16.9	95.7	Max.	672
66	30	43.6	57.7	15.0	3.99	85.8	149.2	5,127	5,462	335	16.3	93.6	Max.	667
67	30	43.6	54.4	14.8	4.03	52.3	121.5	3,690	3,951	261	15.1	91.5	Min.	479
68	30	44.1	60.4	14.8	4.00	51.1	116.4	5,368	5,702	334	17.1	97.5	Max.	691

TESTS ON PELTON WATER WHEEL.

These tests were made on a 4-foot Pelton wheel made by the Pelton Water Wheel Company, of San Francisco. The water supply was furnished by a Duplex Blake Pump, with which the head on the wheel could be varied from 20 to 230 feet. The head was measured by the use of a 6-inch piezometer located in the supply pipe about two feet back from the wheel nozzle. The pressure at the piezometer was taken either by a mercury column or a pressure gauge. The quantity of water used was measured by passing it over an 18-inch weir. The power developed was consumed by a rope brake. The measurement of the power was made by an Emerson Power Scale placed as a coupling between the brake and the wheel shaft in such a way that the only error introduced was that of the scale itself.

Tests Nos. 1–34 were made at varying heads from 23.9 to 210.6 feet. Tests Nos. 37–62 were made under about the same head, and at varying speeds from 199.5 to 228.4 revolutions per minute. The quantity of water passing the weir was calculated by Francis' formula. The theoretical best velocity of the center of the buckets was taken as one half the velocity of the jet.

TESTS OF PELTON WHEEL.

Number of test.	Date.	Duration. (Minutes.)	Revolutions per minute.	Load on power scale.	Water pressure. (Lbs. per sq. in.)	Head on weir. (Feet.)	Temperature of water. °C.	Total head acting on wheel.	Quantity of water passing weir. (Cu. ft. per second.)	Available work. (Horse power.)	Work at power scale. (Horse power.)	Efficiency. (Per cent.)	Velocity of jet. (Feet per second.)	Velocity of center of buckets.	Theoretical velocity of center of buckets.
1	1895. Oct. 28	30	93.0	83.0	10.3	0.2002	22.4	23.9	0.435	1.18	.936	79.4	42.1	18.0	21.0
2	Oct. 2	29	113.5	126.3	15.0	0.2271	20.0	34.8	0.524	2.06	1.74	84.2	50.7	22.0	25.3
3	Nov. 21	20	115.8	115.6	15.3	0.2269	15.8	35.4	0.523	2.10	1.62	77.2	50.6	22.4	25.3
4	Oct. 3	60	131.5	162.2	20.4	0.2476	21.0	47.3	0.594	3 18	2.58	81.2	57.5	25.5	28.7
6	Oct. 4	30	143.3	205.6	25.2	0.2649	21.1	58.4	0.656	4.34	3.57	82.2	63.5	27.8	31.7
7	Oct. 25	30	148.5	194.0	25.4	0.2689	21.1	58.9	0.670	4.47	3.49	78.0	64.9	28.8	32.4
8	Oct. 9	30	159.5	228.7	29.7	0.2735	20.3	68.8	0.687	5.36	4.42	82.5	66.5	30.9	33.1
10	Oct. 24	30	175.5	257.5	35.6	0.2957	21.0	82.5	0.771	7.20	5.48	76.0	74.6	34 0	37.3
11	Oct. 7	30	174.1	255.5	35.3	0.2958	20.9	81.8	0.771	7.15	5.39	75.4	74.6	33.7	37.3
12	Oct. 22	60	186.7	283.9	40.1	0.3069	20.7	93.0	0.814	8.57	6.43	75.0	78.7	36.2	39.4
13	Oct. 7	30	186.7	282.3	40.2	0.2982	21.2	93.2	0.780	8.23	6.39	77.7	75.5	36.2	37.7
14	Oct. 11	30	196.4	343.8	45.0	0.3216	21.0	104.3	0.871	10.29	8.18	79.6	84.3	38.0	42.1
15	Oct. 8	60	193.7	323.3	45.3	0.3196	21.5	104.8	0.865	10.26	7.59	75.7	83.7	37.5	41.8
16	Oct. 9	60	211.6	344.7	50.1	0.3317	20.7	116.1	0.911	11.98	8.84	73.8	88.2	41.0	44.1
17	Oct. 11	30	203.9	380.1	50.4	0.3312	20.6	116.8	0.909	12.03	9.39	78.1	88.0	39.5	44.0
18	Oct. 23	29	216.5	376.6	55.0	0.3380	21.3	127.5	0.936	13.51	9.88	73.1	90.6	41.9	45.3
19	Oct. 14	30	212.8	380.5	55.1	0 3330	21.8	127.7	0.916	13.24	9.81	74.1	88.6	41.2	44.3
20	Oct. 14	30	230.2	385.2	59.9	0.3397	22.0	138.9	0.943	14.83	10.75	72.4	91.2	44.6	45.6
21	Oct. 21	22	228.1	399.4	59.9	0.3422	20.8	138.9	0.953	15.00	11.04	73.7	92.3	44.2	46.1
22	Oct. 23	60	234.8	429.2	65.3	0.3500	21.0	151.3	0.985	16.87	12.22	74.0	95.3	45.5	47.6
24	Oct. 16	60	243.3	457.1	70.5	0.3551	22.5	163.4	1.006	18.60	13.48	72.4	97.3	47.1	48.7
25	Oct. 18	30	245.8	453.5	70.5	0.3574	22.6	163.4	1.015	18.83	13.51	71.8	98.3	47.6	49.1
26	Nov. 4	30	244.7	455.2	70.4	0.3596	20.0	163.1	1.024	18.92	13.50	71.4	99.1	47.4	49.5
27	Oct. 16	30	253.0	479.8	75.0	0.3621	24.1	173.9	1.035	20.36	14.71	72.2	100.1	49.0	50.1
28	Oct. 21	30	252.8	487.8	75.3	0.3644	21 0	174.4	1.044	20.62	14.95	72.5	101.0	49.0	50.5
29	Oct. 18	30	260.7	515.3	79.8	0.3710	22.5	185.0	1.072	22.45	16.28	72.5	103.7	50.5	51.8
30	Oct. 28	60	259.0	518.9	80 7	0.3728	21.7	187.1	1.079	22.86	16.29	71.2	104.4	50.2	52.2
31	Oct. 29	30	264.8	559.4	85.4	0.3819	18.5	197.8	1.118	25.05	17.96	71.7	108.2	51.3	54.1
32	Oct. 30	30	266.8	556.3	85.2	0.3821	19.5	197.4	1.118	25.02	17.99	72.0	108.2	51.7	54.1
33	Oct. 30	30	270.6	588.7	90.4	0.3893	19.9	209.4	1.149	27.25	19.31	70.9	111.2	52.4	55.6
34	Oct. 31	29	274.7	595.0	90.9	0.3891	20.9	210.6	1.148	27.38	19.81	72.3	111.1	53.2	55.5
37	Nov. 6	30	199.5	414.7	55.42	0.3405	21.1	128.5	0.946	13.77	10.03	72.8	91.6	38.6	45.8
39	Nov. 11	30	215.3	394.3	55.90	0.3419	22.0	129.6	0.952	13.97	10.29	73.6	92.1	41.7	46.1
40	Nov. 8	30	216.6	389.4	56.01	0.3402	23.3	129.9	0.945	13.90	10 22	73.5	91.4	41.9	45.7
41	Nov. 15	30	217.1	387.0	55.91	0.3404	21.0	129.6	0.946	13.88	10.18	73.3	91.5	42.0	45.8
42	Nov. 19	30	217 6	384.6	55.82	0.3397	21.8	129.4	0.943	13 82	10.14	73.4	91.2	42.1	45.6
43	Nov. 18	30	218.1	384.6	55.84	0.3414	20.0	129.4	0.950	13.93	10.17	73.0	91.9	42.2	46.0
44	Nov. 15	30	218.6	380 6	55.88	0.3400	21.0	129.5	0.944	13 85	10.08	72.8	91.4	42.3	45.7
45	Nov. 20	30	218.7	382.1	55.69	0.3387	22.6	129.1	0.939	13.72	10.13	73.8	90.8	42.4	45.4
46	Nov. 22	30	218.9	385.4	55.99	0 3413	17.8	129.7	0.949	13.96	10.23	73.3	91.9	42.4	45.9
47	Nov. 18	30	219.3	382.0	55.76	0.3398	20.8	129.3	0.943	13.81	10.15	73.5	91.3	42.5	45.6
48	Nov. 4	20	220.5	376.4	55.58	0.3406	20.0	128.8	0.947	13.81	10.06	72.8	91.6	42.7	45.8
49	Nov. 8	30	220.5	382 0	56.55	0.3409	22.7	131.1	0.948	14.07	10.21	72.6	91.7	42.7	45.9
50	Nov. 11	30	220.9	381.7	55.74	0.3402	21.9	129.2	0.945	13.83	10.22	73.9	91.4	42.8	45.7
51	Nov. 22	30	221.2	382.0	56.03	0.3391	18.7	129.8	0.940	13.83	10.24	74.0	91.0	42.8	45.5
52	Nov. 13	30	221.3	381.9	55.73	0.3410	21.0	129 2	0.948	13.88	10.24	73.8	91.8	42.9	45.9
53	Nov. 14	30	221.3	380.9	55 77	0.3411	21.4	129.3	0.949	13.89	10.22	73.5	91.8	42.9	45.9
54	Nov. 7	30	221.5	375.4	55.60	0.3399	22.6	128.9	0.944	13.77	10 08	73.1	91.3	42.9	45.7
55	Nov. 12	30	222.0	378.9	55.73	0.3397	21.7	129.2	0.943	13.80	10.20	73.9	91.2	43.0	45.6
56	Nov. 13	30	222.9	381.1	55.96	0.3420	21.8	129.4	0.952	13.96	10.30	73.8	92.2	43.2	46.1
57	Nov. 26	30	223.6	365.3	54.96	0.3379	21.1	127.4	0.935	13.50	9.90	73.3	90.5	43.3	45.3
58	Nov. 6	30	224.3	375.8	55.76	0 3410	21.5	129.3	0.948	13.89	10.22	73.5	91.8	43.4	45.9
59	Nov. 25	30	225.0	374.0	55.76	0.3418	18.5	129.2	0.952	13.93	10.20	73.2	92.1	43.6	46.0
60	Nov. 27	30	225.7	369.2	55.71	0.3393	21.7	129.1	0.941	13.76	10.10	73.4	91.1	43.7	45.5
61	Nov. 25	30	226.8	371.5	55.87	0.3424	20.0	129.5	0.954	14.00	10.21	73.0	92.3	43.9	46.2
62	Nov. 27	30	228.4	364.9	55.60	0.3389	21.2	128.9	0.939	13.72	10.10	73.6	90.9	44.2	45.5

Diameter of nozzle . . . . 0.1147 feet. Width of weir . . . . 1.498 feet.
Diameter at piezometer . . . . . . 0.5 feet. Circumference of power scale . . 4 feet.
Diameter of wheel through center of buckets, 3.698 feet.

TESTS ON NO. 6 DOUGLAS HYDRAULIC RAM.

Number of test.	Date.	Duration of test. (Minutes.)	Head on ram. (Feet.)	Discharge head. (Feet.)	Pulses per minute.	Weight of water delivered.	Water fed. (Lbs. per minute.)	Water delivered. (Lbs. per minute.)	Available work. (Foot-pounds per minute.)	Work done. (Foot-pounds per min.)	Efficiency. (Per cent.)	Capacity. (Gals. per hour.
	1896.											
64	Mar. 12	20	4.16	37	50	172	172.2	8.60	716	318	44	62
65	Mar. 19	20	6.5	39	70	307.75	180.9	15.39	1,180	600	51	111
67	Mar. 5	30	5.86	41	62	290	163	9.66	962	396	41	70
69	Feb. 21	30	5.46	46	67	319	166.1	10.30	907	474	52	74
70	Mar. 3	30	5.96	46	66.3	343.5	171.6	11.45	1,020	527	51	88
71	Mar. 2	30	6.0	46	67	365.5	193.5	12.18	1,160	560	48	88
73	Feb. 28	30	6.5	46	73	342	177.9	11.40	1,160	524	45	82
74	Feb. 25	30	5.96	48	70	262	160.7	8.73	958	419	44	63
75	Mar. 20	30	6.0	48	66	264	172	8.80	103	422	41	63
76	Feb. 25	30	6.0	48	70	289	164	9.63	984	462	47	69
77	Mar. 2	20	6.0	48	65	205.7	169	10.29	1,010	494	49	74
78	Feb. 27	30	6.92	48	79	363	160.3	12.10	1,110	581	52	87
79	Feb. 26	30	6.95	51	79	382	207.9	12.73	1,440	649	45	92
80	Mar. 3	30	6.5	53	70	302	172.6	10.07	1,120	534	48	72
82	Feb. 19	30	6.24	57	71	280.2	180.1	9.34	1,120	532	47	67
83	Mar. 10	30	7.12	57	74	306	169.9	10.20	1,210	581	48	73
86	Feb. 20	30	5.98	60	69	222	155.5	7.40	930	444	48	53
87	Feb. 17	30	6.45	60	72	270.5	173.3	9.01	1,120	541	48	65
88	Feb. 21	30	6.7	60	77	274	159.8	9.13	1,070	548	51	66
89	Mar. 6	30	6.58	62	70	204.5	161.3	6.81	1,060	423	40	49
91	Feb. 20	30	6.96	62	75	297.5	175.7	9.91	1,220	615	50	71
92	Feb. 24	30	5.96	69	70	181	154.8	6.03	923	416	45	43
93	Feb. 26	30	6.70	69	75	198.5	154.4	6.61	1,030	457	44	48

TESTS ON A COMPOUND MARSH PUMP, 10″, 16″, AND $9\frac{1}{4}$″ × 16″ STROKE.

The steam used by the pump was condensed in a surface condenser and weighed.

The water pumped was measured, first, by means of an underwriter's fire nozzle either $1\frac{1}{8}$″ or 2″ in diameter; then, after leaving the nozzle, by flowing the water over a weir in the second story of the laboratory, and then again by means of a second weir in the basement. The results by the two weirs agreed very closely, but it will be noticed that there is a slight difference between the quantities by the weirs and by the nozzle.

The total head pumped against was found by adding to the difference in level between the water in the suction well and that in the air chamber the head in feet of water due to the air pressure in the air chamber.

Five indicators were used, four on the steam end and one on one end of the water cylinder. Motion for the indicator was gotten through a pantograph attached to a tail-rod screwed into the water piston and running out through the back head of the water cylinder. The length of stroke and number of strokes were obtained by attachments to this same tail-rod.

TESTS ON A COMPOUND MARSH PUMP, 10″, 16″, AND 9¼″ × 16″ STROKE.

Date.	Single strokes per minute.	Length of stroke.	Steam pressure by gauge.	Weight of condensed steam per hour. (Pounds.)	Total head. (Feet.)	M. E. P. Steam Cylinders. High pressure. (Head end.)	High pressure. (Pump end.)	Low pressure. (Head end.	Low pressure. (Pump end.)	M. E. P. water cylinder.
Dec. 17, 1895	26.0	15.14	29.4	379	86.12	18.04	16.98	8.63	7.26	42.75
Dec. 19, 1895	30.3	15.50	39.6	582	116.23	22.92	21.15	9.72	10.33	52.10
Dec. 20, 1895	33.8	15.75	49.3	804	149.81	25.03	23.05	14.76	13.37	69.63
Dec. 20, 1895	34.3	15.73	49.0	850	150.25	24.88	23.19	15.17	13.75	69.48
Jan. 6, 1896	36.2	15.50	49.3	846	160 52	30.11	29.95	12.99	12.98	73.81
Dec. 30, 1895	36.9	15.62	50.5	871	164.89	30.54	28.20	14.60	13.47	75.31
Dec. 30, 1895	37.3	15.63	49.7	870	169.16	29.71	27.87	14.67	13.90	75.86
Dec. 31, 1895	44.2	15.59	59.3	1,118	202.42	33.75	25.82	15.81	14.17	84.27
Jan. 6, 1896	41.9	15.50	59 8	1,081	198.70	35.72	34.45	14.86	16.13	89.34
Dec. 27, 1895	44.7	15.53	59 8	1,231	197.86	33.98	29.75	15.60	14.28	.....
Jan. 1, 1896	46.5	15.50	69.2	1,300	238.95	40.44	37.28	21.48	20.37	109.08
Jan. 2, 1896	50.7	15.60	78.3	1,536	288.60	39.89	36.20	27.82	27.78	125.03

TESTS ON A COMPOUND MARSH PUMP, 10″, 16″, AND 9¼″ × 16″ STROKE.

Continued.

Date.	Horse power steam cylinders.	Horse power water cylinder.	Horse power output.	Effic'ency. (Per cent.)	Apparent capacity of pump. (Gallons per minute.	Capacity of pump by hose nozzle. (Gallons per min.)	Capacity of pump by weirs. (Average of two.) (Gallons per min.)	Steam per horse power per hour.	B. T. U. per horse power per minute.	Duty. (Foot-pounds per 1,000,000 B. T. U.)
Dec. 17, 1895	5 84	5.61	4.73	81.0	224.8	218.7	217.3	65.5	1,065	25,080,000
Dec. 19, 1895	8.77	8.15	7.42	84.6	268.2	248.9	252.7	66.4	1,083	25,760,000
Dec. 20, 1895	12.53	12.34	10.81	86.3	303.9	291.4	288.0	64.3	1,052	27,070,000
Dec. 20, 1895	12.90	12.48	11.06	85.7	307.8	291.4	292.5	65.9	1,079	26,210,000
Jan. 6, 1896	13.89	13.78	12.44	89.5	320,1	306.8	307.0	60.9	997	29,620,000
Dec. 30, 1895	14.73	14.45	12.89	87.5	328.8	310.2	311.2	59.1	968	29,810,000
Dec. 30, 1895	14.92	14.72	13.44	90.0	332 6	315.9	314.7	58.9	964	30,830,000
Dec. 31, 1895	18.39	19.32	17.22	96.2	393.1	346.4	340.0	60.8	998	31,800,000
Jan. 6, 1896	19.02	19.34	17.48	91.9	371.0	.....	350.2	56.8	934	32,480,000
Dec. 27, 1895	19.07	.....	17.29	90.7	396.4	345.5	346.3	58.7	964	31,030,000
Jan. 1, 1896	26.09	26.17	23.31	89.3	411.3	386.6	385.9	49.8	820	35,920,000
Jan. 2, 1896	33.87	32.96	30.74	90.8	451.9	416.9	422.2	45.3	749	40,000,000

INSTRUCTION IN THEORETICAL CHEMISTRY.[1]

BY ARTHUR A. NOYES, PH.D.

THE rapid development which the science of general or theoretical chemistry has undergone within the past few years has made imperative radical changes in the systems of instruction in that subject. Ten years ago it was necessary, and unfortunately to-day it is still very common, for text-books and teachers of theoretical chemistry to confine themselves almost exclusively to a discussion of the laws and principles underlying the composition of existing bodies, leaving out of consideration entirely the other great division of chemical science which treats of the changes in the composition of bodies. The older courses of instruction treated very fully the chemical significance of the properties of gases, but were obliged to pass over in silence the more familiar class of substances known as solutions. It is not, however, merely in extent alone that the subject has increased in importance. The recent additions have imparted to it a much more practical character, and have brought it into much closer connection with the experimental work of the ordinary chemist. It will hardly be claimed that a knowledge of the Principles of Avogadro, Dulong and Petit, and Mitscherlich, of the Periodic Law, or of the hypotheses in regard to valence, is of much service in enabling the chemical student to understand the facts met with in his daily experience; but an acquaintance with the laws on which depend the familiar phenomena of neutralization, precipitation, solubility, displacement of one acid or base by another, the behavior of indicators, and the like, is of the greatest practical value to him and of almost constant applicability.

On this account it seems to me urgent to emphasize the importance in courses on general or theoretical chemistry of a detailed and thorough consideration of the recent theories of solution and the constitution of dissolved substances, and of the laws of chemical change and equilibrium. It is not sufficient, as is done in some of the recent text-books on the subject, merely to announce the general principle,

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[1] Read at Buffalo before the American Association for the Advancement of Science.

for example, simply to state the fundamental law of chemical statics in the usual formal way, but it is necessary to illustrate it by a great variety of practical applications to known phenomena, until the principle becomes as familiar as the Structure Theory is to the student of organic chemistry. In my opinion, about two thirds of the time available should be devoted to the recently developed portions of the subject. At the Massachusetts Institute of Technology, out of seventy-five hours of classroom work in theoretical chemistry, forty-five are concerned with the phenomena of solutions and of chemical change. Fifteen lectures and recitations are devoted solely to the discussion of applications of the law of chemical equilibrium.

It is unfortunately true that at the present time there is no text-book suitable for an undergraduate student which treats these matters in a satisfactory manner. The teacher can, however, readily obtain the material for such a course from the larger works of Ostwald and Nernst. It may, however, perhaps not be superfluous to enumerate the principal recently developed subjects which ought in my opinion to be considered in an undergraduate college course. They are: The experimental laws of osmotic pressure, vapor pressure, freezing-point lowering and boiling-point raising, and the theoretical relations between them; the abnormal values of these properties in the case of salt solutions, the electrical conductivity and characteristic chemical properties of salt solutions, and the explanation of these phenomena by the Electrolytic Dissociation Theory; the determination of the degree of dissociation of salts from conductivity measurements; the laws of the effect of concentration, temperature, and catalytic influences on the speed of chemical reactions; the law of chemical equilibrium, and the application of it to the phenomena of gaseous and electrolytic dissociation, of solubility effect, of hydrolysis, of the division of a base between two acids, and of indicators; the degree of dissociation and affinity constants of organic acids and bases and other compounds; the effect of temperature on chemical equilibrium; a brief discussion of thermochemical methods and calculations, of the general principles established in the case of the neutralization of acids and bases, of their explanation by the dissociation theory, and of the so-called principle of maximum work; and finally, Faraday's Law of Electrolysis and the relation of electrical and chemical energy in galvanic elements.

It is very desirable that the class-room instruction should be supplemented by laboratory practice. Experience at the Massachusetts

Institute of Technology has shown that a quite satisfactory laboratory course can be given in about thirty hours' time, and, as the apparatus required is not expensive, it would seem practicable to introduce such courses more extensively. The course given at the Institute comprises the following quantitative experiments: Vapor-density determinations by the three methods of Victor Meyer, Hoffmann, and Dumas; molecular-weight determinations with Beckmann's boiling and freezing point apparatus; measurement of the speed of catalysis of methyl acetate by hydrochloric acid; determination of the solubility of one salt in the presence of another; measurements of the electrical conductivity and calculation of the affinity constant of an organic acid; and a thermochemical measurement of the heat of neutralization of sodium hydroxide and hydrochloric acid. It will be seen that almost all these experiments are distinctly chemical in their bearing. Into a more extended course, physico-chemical measurements proper, such as specific gravity, index of refraction, viscosity determinations, and so forth, could be advantageously introduced. In arranging the details of a course like that here described, the teacher will find Ostwald's *Handbook of Physico-Chemical Measurements* of great assistance.

ORIGIN OF PEGMATITE.

By W. O. CROSBY[1] and M. L. FULLER.

Received October 3, 1896.

INTRODUCTION.

THE history of geology is replete with theories of pegmatite, or giant granite — manifold modifications of the agency of water and heat; and this diversity of opinion finds a ready explanation in the fact that in no other class of rocks do we find such a perfect combination of aqueous and igneous characters. Although the intimate association and evident close connection of pegmatite with undoubted plutonic rocks, and their agreement with the latter in composition and relations to the inclosing formations, has led many writers to regard the pegmatite itself as of plutonic igneous origin, it is not long since geologists, from a consideration chiefly of the exceedingly coarse crystallization and frequent comb-structure of the pegmatites, were quite generally united, under the leadership of T. Sterry Hunt, in the conviction that they were true vein rocks, due to the deposition of the various component minerals from solution in open fissures or other preëxisting cavities. Now, however, a decided drift in the opposite direction may again be noted, and the recent literature of the science indicates an approaching consensus of opinion in favor of the

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[1] Nearly three years ago (December, 1893) I read a paper on the "Origin of Pegmatite" before the Geological Society of America, a brief abstract of which appeared in the American Geologist for March, 1894. (See, also, Technology Quarterly, 7, 30–31.) In that paper I developed in outline the modification of Lehmann's aqueo-igneous theory of pegmatite, which is more completely elaborated and substantiated in the present contribution; but its publication was deferred, awaiting an opportunity to more thoroughly test the theory in the field. In the summer of 1895 I was able to spend a few days in the pegmatite district of Grafton and Sullivan Counties, in southwestern New Hampshire, and later in the year Mr. Fuller, a student in the Geological Department of the Massachusetts Institute of Technology, undertook, under my direction, a more extended and detailed study of the pegmatites of that region, basing thereon his thesis for graduation the following June. Mr. Fuller's investigation has materially modified and strengthened the aqueo-igneous theory, and hence this joint production.

W. O. CROSBY.

association of the pegmatites, in their genetic relations, with plutonic igneous rocks rather than with subterranean aqueous deposits. In fact, the view that pegmatite is in some sense an intrusive rock may be regarded as so well established, through the labors of Lehmann,[1] Brögger,[2] Williams,[3] and others, that the theories of lateral secretion and aqueous deposition are fast becoming of merely historical interest.

This modern view is more acceptable than any of its predecessors mainly because it is less extreme. It is a reaction toward the igneous category, but the pendulum has not swung so far as to wholly exclude the aqueous influences. In short, the new theory is not simply a revival of the old, but it is essentially a combination or compromise — neither igneous nor aqueous, but aqueo-igneous. The modern conception is that in a broad view the pegmatites are igneous rocks, but it is the part which water has played in their formation that has so strongly differentiated them from other igneous types. Although we shall incidentally apply the touchstone of observed facts to all the principal hypotheses, the chief purpose of this paper is a contribution to the aqueo-igneous theory.[4]

The term pegmatite has been employed heretofore in two senses: To designate (1) the macro- and micro-pegmatitic or graphic-granite structure in rocks; (2) a distinct type of coarsely crystalline plutonic rocks, which is characterized only to a slight degree by the pegmatitic or graphic structure, but is especially distinguished, as a rule, by the gigantic scale of its crystallization. It is, of course, in the second sense that the term is employed here. We desire, however, to direct attention at the outset to two prominent facts which appear to us to demand a modification of the definition. First, the pegmatites have a wide range in composition, from the most highly acidic of all rocks (pure quartz) to ultra-basic varieties, giant granite being an appropriate trivial name only for some of the more acid forms. Second, the differences between the pegmatites and the more normal plutonic rocks are textural to a much greater degree

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[1] Ueber die Entstehung der alt krystallinischen Schiefergesteine, 1884, p. 24 *et seq.*

[2] Die Mineralien der Syenitpegmatitgänge der südnorwegischen Augit und Nephelinsyenite, 1. Theil, pp. 215–225. For translation, by N. N. Evans, see Canadian Record of Science, **6**, 33–46 and 61–71.

[3] "Origin of the Maryland Pegmatites." Fifteenth Annual Report United States Geological Survey, pp. 675–684.

[4] The contributions of Brögger and Williams, already referred to, are replete with references, and render citations of the earlier literature unnecessary here.

than mineralogical or chemical. In other words, since the classification is based primarily upon composition (the result of magmatic differentiation), pegmatite should be regarded, not as a distinct species or family of rocks, but rather as a possible textural phase of all, or nearly all, the plutonic rocks ; and we may in general say of any plutonic rock that it may be cryptocrystalline, microcrystalline, macrocrystalline, or pegmatitic. Our problem is, then, to account for the pegmatitic phase of the plutonic rocks. While there can be little or no doubt that the acid and basic pegmatites have had a common origin, every student of geology knows that the acid types have been far more generally and extensively observed and exploited, and hence more fully and satisfactorily described, and our own field studies, as already indicated, have been limited chiefly to this class. The conclusions stated in the following pages are to be understood, therefore, as applying especially to the acid pegmatites.

CHARACTERS OF THE ACID PEGMATITES.

A complete description of the acid pegmatites is not intended here, but simply an enumeration of the chief features which any satisfactory theory of their origin must explain.

Composition. — The acid pegmatites, like the corresponding normal plutonic rocks, consist of anhydrous silicate species, and usually more or less of free acid (quartz) and traces of free bases (iron oxides, cassiterite, etc.), apatite being, perhaps, the most conspicuous exception, although the complete list of the pegmatite minerals includes also titanite and various niobates, tantalates, and tungstates. The great disparity as regards abundance makes possible a quite sharp distinction between the so-called principal or essential, and the rarer or accessory, species. The essential species include quartz ; the acid feldspars — orthoclase, oligoclase, albite, and microcline — the last two being especially characteristic ; and the more acid micas, including muscovite and lepidolite and, less characteristically, biotite. The accessory minerals are more numerous, in some cases more distinctive, and especially remarkable for the large proportion of rare species or species that are rare or wholly wanting in all other rocks. A single mica mine in New Hampshire (the Ruggles Mine in Grafton) is said to have afforded sixty-one minerals, and it is undoubtedly true that the list of known silicate species is considerably longer than it would be if these natural cabinets, or storehouses of fine minerals, had never been studied.

The quartz of pegmatite, as of ordinary granite, is especially characterized by numerous inclusions of water and carbon dioxide. The proportion of carbon dioxide to water has been proved to be so high in some cases — for example, nearly 1 to 1 in the quartz of the Branchville, Connecticut, pegmatite — as to indicate that the crystallization took place under enormous pressure.[1]

Our observations abundantly confirm Williams' statement[2] that the most typical pegmatites are intimately associated with, and pass gradually into, bodies of pure quartz and ordinary quartz veins. But we cannot agree with this writer in drawing across this undoubted gradation an arbitrary line of demarcation as regards origin. On the contrary, we feel that the true theory of pegmatite must recognize this obvious relationship to quartz veins, by making of the latter a possible end-product of the same great process of differentiation which yields the former. In other words, some quartz veins are on the same road that lead to pegmatite, but a little farther along, at the end of the road. On the west side of Narragansett Bay, opposite Conanicut Island, there is, in the cliffs known as the Bonnet and Packard Rocks, a series of mica schists backed by normal granite and traversed by numerous very typical veins of pegmatite 5 to 50 feet wide. A mile to the eastward, on Dutch Island, the veins in the schist are quartz with some feldspar but no mica; while on the west shore of Conanicut Island, so far as observed, they are quartz alone. Van Hise has noted a similar gradation in the character of the pegmatite veins intersecting the schists which envelop the granite core or batholite of the Black Hills, the veins changing gradually from typical pegmatite near the granite to ordinary quartz veins at a moderate distance. (*16th Annual Report United States Geological Survey,* Part. I, p. 688.)

Relations of Composition to the Inclosing Rocks. — Broadly speaking, the pegmatites are independent of the wall rock in composition. In New Hampshire we have found pegmatites of strikingly uniform composition traversing in succession and without sensible change a whole series of granites, gneisses, and schists of the most diverse character. Brögger and Williams have specially noted this indiffer-

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[1] A. W. Wright. American Journal Science, March, 1881.

[2] United States Geological Survey. Fifteenth Annual Report, pp. 678 and 679.

ence of the pegmatites to the character of the inclosing formations. The former[1] cites as examples the acid pegmatites of Hitterö, which cut a very basic (labradorite and anorthite) rock, and those of Rudemyr cutting Silurian schists and limestones, and the latter[2] speaks of the acid pegmatites of Maryland as occurring in gabbro and peridotite and extending from gneiss into limestone without sensible change.

The one important exception to this principle is found in the fact which lies at the foundation of the modern theory of pegmatite, viz., that in every pegmatite district there is one normal plutonic rock of essentially similar but slightly less acid composition, with which the pegmatite is most intimately associated, into which it may often be traced, and from which it has evidently been derived. That is, the pegmatites are contrasted with the inclosing formations in all cases except where they traverse the plutonic mass of which they are the most highly differentiated phase or end-product. Brögger and Williams lay much stress upon this fact and cite abundant illustrations of it, noting especially that the pegmatite is more acid than the parent mass. Williams says of the pegmatite dikes of Maryland, "They agree essentially in chemical and mineral composition with the granite masses whose igneous origin is well established, although they are in the main somewhat more acid than these, and their size and abundance are directly proportioned to their nearness to some eruptive granite mass. At many localities they can be seen to decrease steadily both in number and size as they recede from such a granitic boundary." The more acid character of pegmatite than of granite is seen in the fact that among the micas biotite largely predominates in granite, and is the exception in pegmatite.

The parent plutonics of the pegmatites which we have studied in New Hampshire are the Concord granite, and the Montalban gneiss, the latter seeming to be merely a more gneissoid phase of the former. These two granitic types, it may be added, are readily proved by the field evidence to be the youngest and most acidic of the entire granitic series of the region, the facts pointing very plainly to a progressive chemical differentiation of a vast body of magma during a long period, with, at the end, a marked textural differentiation. In New

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[1] Canadian Record of Science, **6**, 36 and 37.

[2] U. S. Geol. Survey, Ann. Report, **15**, 683.

Hampshire we have not found the pegmatite so abundant in the Concord granite or any plutonic formation as in the fibrolite and other schists, which are easily proved to antedate all these igneous rocks. This is due in part, probably, to the fissile and flexible character of the schists, by virtue of which they offer an easier passage to intrusives than do the more massive formations; and in part, no doubt, to the relative readiness with which they are dissolved or melted away by the invading magma. It may be added that in the schists, as in the gneisses and granites, the amount of pegmatite is, in general, inversely proportional to the distance from the Concord granite.

It is a reasonable expectation that the absorption of great bodies of schist should affect the composition of the pegmatite. In fact Geikie says (*Text-Book of Geology*, p. 302), igneous rocks dissolve or eat away the inclosing formations, and in consequence vary considerably in composition from place to place. The schists are poor in alkalies, being composed chiefly of silica and alumina; and their absorption by the pegmatite magma would obviously tend to make the pegmatite richer in quartz and muscovite, as the following comparison of the alkaline silicates shows, the formation of a pure aluminum silicate being impossible in the presence of alkalies.

Orthoclase, SiO_2, 64.7; Al_2O_3, 18.4; alkalies, 16.9
Muscovite, SiO_2, 46.5; Al_2O_3, 33.9; alkalies, 10.0.

This is in harmony with our observation that the mica mines of New Hampshire, and so far as we are able to learn of other regions, are chiefly in the schist series, and we believe that in general the pegmatite is more micaceous in the schists than in the granite. It may be that we have here an explanation of greisen — that rather anomalous aggregate of quartz and mica. Lepidolite has been noted as a specially characteristic feature of pegmatite, and the fact that it also occurs in greisen is certainly suggestive of the genetic relationship of the two rocks. We also venture the suggestion that perhaps pegmatite rich in tourmaline, and tourmaline or schorl rock (tourmaline and quartz) may be explained in the same way, tourmaline representing a still greater dearth of alkalies — 2 to 4 per cent.

Although this close agreement in composition between pegmatite and its parent plutonics certainly holds for the principal component minerals, the two types seem to be contrasted as regards their rarer or accessory constituents, pegmatite being much richer in these than granite. G. vom Rath, in his account of the celebrated pegmatite veins of Elba,[1] says that the "tourmaline, beryl, lithia mica, etc., are foreign to normal granite," and that "these veins, on account of their wealth in rare and peculiar minerals, which for the most part are wanting in the wall-rocks, necessitates the assumption of a special mode of formation quite different to that assumed for the wall-rock." That the rare species are a more conspicuous feature of pegmatite than of granite is obvious, but that they are absolutely much more abundant when large volumes of rock are compared, has certainly not been proved, and is at least doubtful. The same slow process which builds the giant crystals of spodumene, beryl, etc., must tend to gather the materials from a large volume of magma. In other words, although in the number and variety of the accessory minerals the pegmatite veins far exceed the known species of the normal granites, we have good reason for believing that in these rarer or accessory as well as the more abundant or principal minerals, the two types are essentially similar if not almost identical, or at least that bulk analyses would show a substantial agreement in chemical composition. Substances which are so sparingly and thinly diffused in the normal granites as to be almost or quite inappreciable are, if not actually concentrated in the pegmatite, developed in a more concrete and tangible form.

Texture. (*Crystallization.*)—Undoubtedly the most distinctive and striking feature of the pegmatites is the crystalline structure, which is, in general, on a remarkably coarse or gigantic scale, and unparalleled among the sedimentary and normal igneous rocks. Well formed crystals of feldspar and mica, and even of such rare accessories as beryl and spodumene, from 6 inches to a foot or more in diameter, are normal occurrences. In fact, as regards the size, perfection, beauty, and variety of the specimens which they afford, the pegmatites are, more than all other rock formations taken together, the great repositories of crystallized silicates, as every good mineral cabinet testifies; and it is thus easy to understand why the pegmatite veins are objects of the highest interest to students of mineralogy. An examination of the mineral localities of New England and Canada, not to take a broader view, would undoubtedly show that a very large majority of the more interesting occurrences are in acid or basic pegmatites.

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[1] Die Insel Elba (Geogn.-min. Fragmente aus Italien, VIII) in Zeitschr. d. d. geol. Ges., 1870, **22**, 649.

The maximum crystallization is indicated by the great beryls from a foot to a yard in diameter in the mica mines of New Hampshire, the largest known example of which is in the Museum of the Boston Society of Natural History, and the gigantic spodumenes from 10 to over 30 feet in length, and from a foot to a yard in diameter, in the tin mines of the Black Hills. In the pegmatites of New Hampshire we have frequently observed feldspars ten feet or more in length, and one crystal in the American Mine in Groton measured fully 20 feet; while Brögger mentions[1] feldspar individuals more than 10 meters (nearly 33 feet) in length. It is, of course, by virtue of the large scale on which the crystallization has taken place that the pegmatite veins are not quarried for granite, but rather to obtain mica, feldspar, and quartz for commercial purposes, these and many rarer species for mineral cabinets, and tourmaline and other gems.

Brögger[2] also points out that coarseness of crystallization alone does not "condition the pegmatitic nature of the veins, nor is even necessarily present in order to justify the appellation pegmatitic. It is the habitus as a whole which determines this." Nevertheless, this giant granite texture is very constant, and clearly, as already stated, the most distinctive and essential character of pegmatite. One fact to be specially noted is that the coarseness of texture or scale of crystallization is not proportional to the size of the masses, for dikes and bosses hundreds of feet wide may be finer grained than those 5 to 20 feet wide. Thus the great boss of pegmatite forming Mt. Tug, in Orange, 500 feet wide and 1,500 feet long, is relatively fine-grained, while, as marking the other extreme, we recall a vein in Groton less than 2 feet wide containing stout crystals of feldspar 20 inches broad.

Next in order stands the irregularity of both the mineral composition and texture. The normal plutonics are remarkably even grained and uniform mixtures of the component minerals; but in the pegmatites the principle of segregation has evidently had almost unrestricted play, and irregularity is the rule. It is difficult to do justice to this somewhat indefinite character in words; but every one who has observed pegmatites in the field will fully appreciate it. As noted by Brögger,[3] the finer grained portions of the pegmatite often become eugranitic and indistinguishable from the parent plutonic.

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[1] Canadian Record of Science, **6**, 67.

[2] Ibid., 69 and 70.

[3] Ibid., **6**, 64.

The order of crystallization of the various minerals in pegmatite is the same as for the normal plutonics — tourmaline (and other basic species), biotite, muscovite, basic feldspar, acid feldspar, and quartz — and equally constant, (Figure 1). Pegmatite agrees with the normal plutonics, also, in the approximately idiomorphic character of the earlier crystallizations, the quartz being always allotriomorphic. In the vugs and pockets of the pegmatite veins, however, the order of crystallization is reversed, except for tourmaline and other ultra-basic species, and the quartz is idiomorphic. This reverse order is well shown in the abundant association of albite and muscovite in the pockets of the pegmatite veins of Groton, Orange, Grafton, and other towns. The albite occurs as distinct tabular crystals (clevelandite) projecting into the cavity; and implanted on the albites are the muscovites. Notwithstanding the lateness of its crystallization, the quartz not infrequently forms immense vitreous masses (Figure 2), and these often pass into veins of quartz, or quartz and accessory feldspar, intersecting the normal pegmatite as well as the country rock (Figure 3), thus testifying clearly to the extremely acid character of the magma residuum.

Rosenbusch has sagaciously correlated the pockets and druses with the miarolitic structure of the normal plutonics — a feature of like significance, but developed, like the crystallization, on a grand scale. Evidence of contemporaneous crystallization is abundant in all the larger masses, the crystallization of the later species having begun before that of the earlier ceased. It is sufficient to merely mention the unique example of this which we have in graphic granite. A tendency to this regular intergrowth of quartz and feldspar is frequently manifested; but it rather rarely attains to its ideal development. The perthitic intergrowth of the feldspars has, apparently, a like significance. When the earlier crystallizations assume slender, prismatic forms, as is notably the case with tourmaline, the subsequent hardening and crystallization of the silica (quartz) involves not only the inclosure, but also the distortion and breaking, of the guest crystals.

Structure. — It is among the varied structural phases of pegmatite that aqueous and igneous characters — the features of veins and the features of dikes — are most perfectly blended. The pegmatite masses, like true dikes, are frequently fine-grained next the wall, becoming rapidly coarser toward the center. Where the inclosing formation is the parent plutonic, the fine-grained portion, as previously

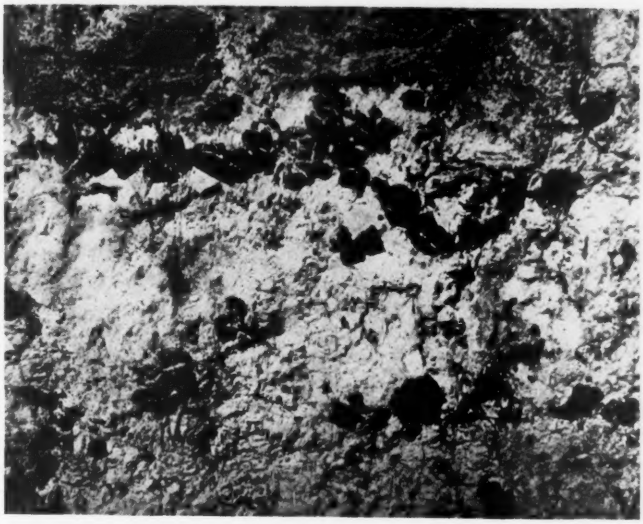

Fig. 1. Tourmaline in Pegmatite on and near the Wall-Rock (Mica Schist)
Chandler's Mills, N. H.

Fig. 2. Mass of Quartz in Pegmatite.
Osgood's Ledge, Acworth, N. H.

noted, sometimes becomes eugranitic and grades into the wall-rock without any line of demarcation. This contact zone of the pegmatite masses is, perhaps, the most usual phase of the banded structure to which the advocates of the aqueous theory attach so much importance. Brögger says,[1] "The zonal structure, when any such is present, which, however, is generally not the case, usually makes itself evident only in a finer-grained condition of the vein boundaries, and sometimes (especially in the case of granitic pegmatite veins) in a zone with graphic structure next the fine-grained eugranitic marginal zone, upon which there frequently follows (especially in acid granitic pegmatite veins) in the middle of the vein a tremendous size of grain, here often with special enrichment in rarer minerals and also (particularly in acid veins) not seldom with open or distinctly drusy cavities filled with peculiar mineral deposits." All this accords with our observations; but, besides this pseudo-banding, there is a true vein-banding closely akin to that of undoubted aqueous formations. This, however, is of rather rare occurrence; and, according to our observations, mostly confined to the narrow, linear, crack-filling veins, such as abound in the Concord granite. We are unable to agree with Brögger that this banding is always distinct from that of true veins, "inasmuch as the outer zones pass continuously into the inner." We will only cite a single instance; but this appears to be typical. In the Museum of the Boston Society of Natural History is a complete cross-section specimen from a well-defined linear vein of pegmatite in Chesterfield, Mass. The width of the vein is six to seven inches; and it is made up of two sharply defined and symmetrical bands or layers of albite (clevelandite), with the tabular crystals set edgewise to the walls, and a median band of smoky quartz; while springing directly from either wall and penetrating both the albite and quartz are numerous slender prisms of green and red tourmaline. The order of crystallization is clearly marked; and it is very obvious that in this instance the successive periods or generations did not overlap. The minerals were deposited strictly in succession, although, for that matter, a certain amount of contemporaneous deposition is common enough in true veins.

The disposition of the tourmalines noted above is highly characteristic; and may be observed in many massive or unbanded veins;

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[1] Canadian Record of Science, 6, 66.

showing that this comb-structure and a distinct banding are not necessarily correlative, although they are undoubtedly of like significance, testifying with equal distinctness to successive crystallization. The comb-structure is also observable in the disposition of other prismatic minerals and of such tabular species as mica and albite, which are almost invariably set edgewise or perpendicular to the walls in veins of regular form and structure.

Although occurring but sparingly, vugs or pockets and druses are to be regarded as highly characteristic and significant structural features of pegmatite—interesting and entirely normal possibilities of the pegmatite process. In the New Hampshire pegmatites we have found them almost exclusively in the larger veins and masses; and some of these are of large dimensions, as may be inferred from the fact that a pocket in the Palermo Mine, in Groton, has afforded a well-formed crystal of quartz about a yard in diameter. These great pockets are wholly irregular in form, and seem to have no definite position in the vein, except that they are never peripheral. In other districts, pockets in narrow and distinctly linear veins have been observed. These are flatly lenticular in form and, except mineralogically, in no wise distinguishable from the pockets of ordinary mineral veins.

Inclosed fragments of the wall-rock are an exceedingly common and characteristic feature of pegmatite; and the inclusions are, almost without exception, as so commonly in the normal plutonic rocks, in perfect agreement in position and orientation of the lamination or other structural features with the adjacent wall-rock. This peculiarity of the inclusions, although not absolutely incompatible with the aqueous theory of pegmatite, certainly accords best with the plutonic igneous theory. In two instances only have we observed inclusions that appeared to be foreign to the immediately adjacent part of the wall; viz., in small veins near the Palermo Mica Mine of North Groton and in the southern part of Grafton. In both cases the foreign inclusions are of the dark hornblendic Bethlehem gneiss, while the wall-rock is fibrolite schist in the first instance and the coarse porphyritic granite in the second.

In many cases the inclusions, especially of schist, have an exceedingly frayed-out and skeleton-like appearance, suggesting a differential solvent action and shredding rather than mere mechanical breaking or cracking. The wall itself is often similarly affected, as well as more or less distinctly impregnated with tourmaline and other minerals of the first crystallization. This is perhaps the most significant of all the contact phenomena coming under our notice.

We have not observed any clear examples of the centric or spheroidal structure described by L. von Buch and others, and so strongly insisted upon by Brögger; nor has the rare fluidal structure cited by Brögger[1] come under our notice. But we have noted one fact which very plainly suggests motion in the mass during the crystallization of the pegmatite. In a small vein in the Winnepesaukee gneiss north of Honey Brook, in Acworth, the tourmalines, which extend about two-thirds of the way across the fissure, are for a distance of many feet tilted uniformly from the perpendicular to the wall about thirty degrees. This tilting is real and cannot be explained by any irregularity of the walls.

External forms and formal relations to inclosing rocks. — With pegmatite, as with pretty much all subterranean formations, form is less distinctive and significant than structure or composition; and the morphologic argument is rather evenly divided between the rival theories—aqueous and igneous. In general, the occurrences are dike-like in form; but they may with equal propriety be described as vein-like.

No doubt the spaces or cavities occupied by the pegmatites are chiefly mechanical in origin — spaces of discission; and they must, therefore, be conditioned by the structure of the inclosing rocks and the nature of the disrupting force. The more regular masses may be described as rectangular (Figure 4), wall-like (vertical sheets), lenticular (Figure 5), or tabular (horizontal sheets); but a very large proportion of the occurrences are too irregular to come under either of these terms (Figure 6). They very commonly conform closely with the structure planes of the schistose rocks (interbedded veins); but they also intersect the bedding planes or lamination at all angles; and may in general be assumed to follow lines of least resistance to the disrupting force.

We were surprised to find that the cavities occupied by the pegmatite are, on the whole, more crack-like (parallel sides, definite angles, and general linear character) and more plainly suggest a mechanical or disrupting force in the massive rocks than in the bedded and

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[1] **Canadian Record of Science, 6, 64 and 65.**

schistose rocks; and for many of the pegmatite masses in the schists the mechanical explanation is entirely inadmissible, the pegmatite having evidently made room for itself by dissolving and absorbing considerable volumes of schist — spaces of dissolution. We have a magnificent example in the great body of pegmatite at the Ruggles Mica Mine, in Grafton. It has great breadth in the vertical schists, and the schists, without change of dip, completely cover the pegmatite, the bedding planes ending downwards squarely against the approximately flat upper surface of the great boss or stock of pegmatite (Figure 7). Evidently, no theory of pegmatite can be regarded as adequate which fails to take account of both of these diverse causes of the cavities — rifting and solution.[1] Still a third cause must be invoked where the pegmatite is inclosed in, and blends with, the parent plutonic rock.

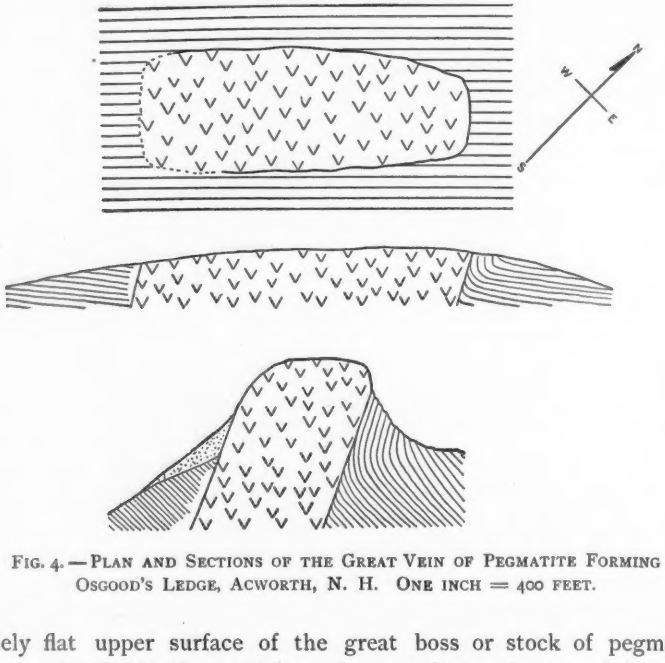

FIG. 4. — PLAN AND SECTIONS OF THE GREAT VEIN OF PEGMATITE FORMING OSGOOD'S LEDGE, ACWORTH, N. H. ONE INCH = 400 FEET.

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[1] According to the observations of Delesse, volcanic rocks, when reduced to a molten condition, attack briskly the sides of the Hessian crucibles in which they are contained and even eat through them.

Fig. 6. Irregular Vein of Pegmatite in Winnepesaukee Gneiss.
Honey Brook Ledges, Acworth, N. H.

Fig. 8. Veins of Quartz and Pegmatite in Mica Schist.
Croydon Mt., Grantham, N. H.

Although, as indicated, certain more or less definite terms may be applied to the pegmatite masses, the great majority are decidedly irregular and indefinite in form. In every instance the pegmatite is clearly younger than the foliation of the inclosing rocks. The masses vary in size from almost miscroscopic veinlets, which, as Williams[1] has pointed out, show a high degree of liquidity in the original magma, up to bosses or dikes 500 feet or more, in width. So far as we have observed, the largest masses show a tendency to the rectangular type. These include Mt. Tug, Orange, 500 x 1,500 feet; Osgood's Ledge, Acworth, 175 x 700 feet; Palermo Mine, Groton, 200 x 500 feet.

Some of the rectangular forms are probably blunt lenses. The lenticular form is also very typically developed in some of the larger masses, such as the great veins on Crystal Mountain, Lempster, 80 x 300 feet, and Trow's Hill, Sunapee, 50 x 400 feet. We have already noted that the pegmatite dikes become smaller and fewer away from the parent mass of granite. The minor lenticular veins, isolated lenses or eyes, conforming with the foliation of the schists, present an interesting problem as to the source and mode of introduction of the component minerals (Figure 8).

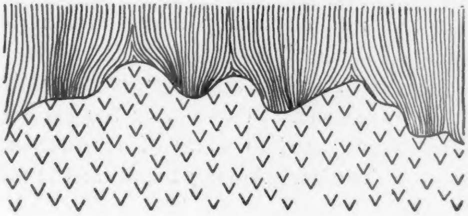

FIG. 7 — VERTICAL SECTION OF PEGMATITE AND OVERLYING SCHIST. RUGGLES MINE, GRAFTON, N. H.

AQUEOUS THEORIES.

All subterranean aqueous deposits may be referred to three classes: veins, impregnations, and substitution deposits.[2] The second and third classes may safely be set aside at once as incapable of throwing any light upon the origin of pegmatite; unless, indeed, the solution and absorption of a body of schist by molten magma be regarded as a mode of substitution. It is sufficient for our present purpose to recognize the two main types of veins: (1) endogenous veins formed chiefly by ascending solutions in fissures or cavities; (2) exogenous veins,

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[1] U. S. Geol. Survey, Annual Report, 15, 681.

[2] Technology Quarterly, 7, 27–48.

formed chiefly by lateral secretion in rocks devoid of sensible fissures or cavities. The characters of the endogenous or fissure veins are well known, the most significant, perhaps, being the banding or crustification, comb-structure, and pockets. The exogenous or segregation veins are especially characterized by their homogeneity of composition and structure and the absence of pockets.

The view that pegmatite masses are, in origin, akin to mineral veins, originally proposed by Saussure, has in recent years been most positively asserted and strongly defended by T. Sterry Hunt. He held[1] that the pegmatites have been formed by the successive deposition of mineral matter from solution, usually in open fissures; and in the development of the genetic hypothesis[2] he states that "the gneisses and bedded granites are to granitic veins (pegmatite) what beds of chemically deposited limestone and travertine are to calcareous veins."

In reviewing the characters of pegmatite, a goodly proportion are found to be common to one or the other of the two types of veins noted above; and to admit of explanation, therefore, by the purely aqueous theories. Among these are the following: (1) rare minerals; (2) coarse crystallization; (3) banding and comb-structure, with tourmalines, etc., normal to the walls; (4) inclusions of water in quartz, etc.; (5) pockets and druses. On the other hand, vein formation does not satisfactorily explain: (1) the order of crystallization, except in pockets; (2) completely idiomorphic crystals; (3) the graphic structure; (4) the finer crystallization next the walls, at least this is more suggestive of igneous contacts; (5) broken tourmalines, etc.; (6) inclined tourmalines; (7) inclusions of carbon dioxide; (8) immense size of many of the veins; (9) evidence of solution of the walls; (10) orientation of inclusions. The characters of the first list point unequivocally to the intervention of water in the formation of pegmatite; while those of the second list demand with equal distinctness important modification of the aqueous process.

IGNEOUS THEORIES.

One of the earliest, and at the same time one of the clearest and most satisfactory, statements of the igneous theory of pegmatite is

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[1] Notes on Granitic Rocks, Amer. Jour. Sci., III, 2, 89.

[2] Mineral Physiology and Physiography, 1886, 133.

that by Charpentier (1823). He held that the pegmatites are "injections of granitic material, which, originating in the still fluid granite, deep down, was pressed into the cracks of the already solidified granite above — afterbirths, as it were, of the same granitic formation in the district of which they occur."

This idea was accepted by De la Beche, Bronn, Fournet, Durocher, and Angelot; and Naumann[1] regarded it as the most probable theory.

Brögger quotes Charpentier's view approvingly; and his own paper, one of the most notable of the later contributions to the literature of pegmatite, is essentially a defense and farther development of this early igneous theory. He reviews critically the views of other writers, and argues strongly in favor of magmatic solidification, holding that it affords satisfactory explanations of the chief facts of composition, texture, structure, and relations to the inclosing formations.

That water plays a more or less essential part in the formation of igneous magmas, at least those of acid character, is now so generally conceded that it would be idle to advance arguments against the view that pegmatite is the product of dry fusion. In fact it would probably be difficult to prove that any of the so-called igneous rocks, have resulted from strictly anhydrous processes. The real question is, then, can acid pegmatites be regarded as the direct product of such a slightly aqueo-igneous fusion or magma as yields the normal granites? It appears to the writers that a sufficient answer to this question is to be found in the characters of granite — a fine and even-grained rock of remarkably uniform composition and devoid of pockets. This absolute lack of agreement in the fundamental characters seems to render a more detailed comparison superfluous. It is thus obvious that the igneous theory also, although accounting satisfactorily for the order of crystallization in pegmatite, broken crystals of tourmaline and beryl, parallel orientation of inclusions, etc., requires important modification, and especially a larger intervention of water; for it does not appear that the variation of any other factor, such as pressure or temperature, would meet the necessities of the case.

Brögger, however, among recent writers, seems disposed to minimize the influence of water; and in the differentiation of pegmatite from normal granite to allow it practically no part whatever. He

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[1] Lehrbuch der Geognosie, 2d. Ed., 2, 232 (1858).

says[1] "the principal requirement for the solidification of deep-seated magmas to holocrystalline plutonic rocks seems, therefore, to consist in a sufficiently slow cooling of the water-bearing magma, under a pressure of superimposed matter great enough to prevent the water separated out by crystallization from freely escaping to the surface, and compelling it by a pressure exerted from above to pass into the wall-rock (contact metamorphism)." Although so clearly recognizing the presence of water, and using it to account for certain contact phenomena, he does not, apparently, regard it as in any way essential to magmatic differentiation, either chemical or textural, but treats the magma, virtually, as if it were anhydrous throughout its entire history; and yet he repeatedly invokes the aid of certain "agents mineralisateurs," which are nowhere more explicitly designated or described. His non-utilization of the water in the magma, obliges him to refer the gigantic crystallization and irregular composition so characteristic of pegmatite wholly to the slowness with which it has cooled and solidified. He says[2] "both when they (the pegmatites) occur in the main mass of the allied eruptive rock (parent plutonic), and when they occur in the neighborhood — and one of the two is always the case — we may assume that the rock surrounding the vein-stone (pegmatite) was first heated to a high temperature and that, therefore, the cooling must have taken place unusually slowly and uniformly; and upon this fact primarily the largeness of the grains may be explained."

This explanation of these extremely important characters, which no theory of pegmatite can ignore, appears to us singularly inadequate, in view of the following considerations: (1) The surrounding rocks must always be cooler than the great body of granitic magma by which they are heated. (2) The coarsest pegmatite is often in narrow dikes thousands of feet if not miles distant from the border of the plutonic mass in which it originated. (3) If, as Brögger insists and we believe, pegmatite is the end-product or final crystallization of the original granite magma, we are, to paraphrase his criticism of Lehmann (p. 43) led to the remarkable result that a body of magma solidifying as the result of cooling has a higher temperature and therefore crystallizes more slowly and coarsely in the later than

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[1] *l. c.*, 45.

[2] *l. c.*, 67.

in the earlier stages of the process. (4) Brögger holds that the most typical pegmatite may be, and in special instances cited by him must have been, formed at very moderate depths below the earth's surface — a few hundred feet to two or three thousand feet. How, under these conditions, the vast body of granite magma at greater depths and cooling far more slowly escaped conversion into pegmatite is a mystery which he nowhere offers to explain.

But he goes on to say[1], "That this explanation of the coarse grain and of the imperfect zonal structure of many pegmatite veins is correct, is rendered probable in the highest degree by the frequent occurrence of pegmatitic structure in those portions of rock bordering on the open drusy cavities of many massive granites. Interpret these as analogous to the formation of the pegmatite veins themselves, in the following way: First, on account of the contraction due to crystallization of the rock already for the most part solidified, there were formed crystal-free *lumina* (microlitic structure on a large scale); the mixture of magma and crystals so formed, which must have constituted a somewhat solid rock, inclosing the lumina, was however completely permeated by the magma, and with this these crystal-free spaces would naturally have been filled. By continued cooling this magma, beginning at the walls, also crystallized out slowly and uninterruptedly, often mixed with minerals which had been formed by special 'agents mineralisateurs;' the conditions of such crystallization, proceeding from the walls of the *lumina* inwards, must have been somewhat different from those of the former crystallization, which took place within the mass of the whole solidifying rock-matter, where the separate individuals must have crowded upon one another, etc.; hence the ever increasing size of grain, the zonal structure (conditioned by the crystallization from the walls inward), etc. If the magmatic silicate solution were not concentrated to such an extent that the *lumina* were completely filled by its crystallization, first, open drusy cavities must have resulted, which finally through continued circulation might be filled in with minerals deposited from solutions at first still hot but later less and less hot. The filling up of the drusy cavities corresponds according to this interpretation pretty exactly to the complete vein formation of the pegmatitic veins which occur outside the normal-

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[1] *l. c.*, 67.

grained rock mass; the explanation throws light in both cases upon the continuous transition from the rock formed purely by magmatic solidification to the final minerals of the druses deposited from solutions not exactly magmatic (less concentrated)."

This statement certainly leaves much to be desired in the way of clearness, and we confess ourselves unable to gather from it with certainty the author's meaning. Considered simply as a suggestion or outline of the mode of formation of pockets, we should not care to criticise it. The references to more and less concentrated magmatic silicate solutions suggest the possible intervention or agency of water; but in view of the facts that this is not explicitly stated and that anhydrous magmas are now generally regarded as true solutions, the idea of minimizing the aqueous influences is obvious. Whether Brögger should really be classed with the advocates of the igneous or the aqueo-igneous theory of pegmatite is ,therefore, doubtful; and it has seemed best to us not to hazard a guess as to the possible hidden meaning of his language.

AQUEO-IGNEOUS THEORY.

Although the igneous theory, even in its more modern forms, so obviously fails as a complete explanation of pegmatite, yet it is distinctly along this line, from Charpentier's view as a starting point, that we have advanced to the conception of a more perfect cöoperation of heat and water. Referring to William's summary[1] of pegmatite theories we learn that Élie de Beaumont, in his famous essay "Sur les emanations volcaniques et métalliferes,"[2] while accepting in the main the igneous and intrusive origin of pegmatites, introduced an important addition in assuming water and other mineralizing agents as necessary factors in their formation. Scheerer,[3] in a contemporary paper, attributed a still more important rôle to water in the formation of pegmatites, holding what Hunt[4] has designated as the theory of "granitic juice," a highly heated aqueous solution of mineral substances impregnating the congealing mass and oozing out under pressure into the surrounding rocks. Lehmann,[5] in his

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[1] U. S. Geol. Survey, Annual Report, 15, 676.

[2] Bull. Soc. Géol. Fr. (II), 4, 12 (1847).

[3] Bull. Soc. Géol. Fr. (II), 4, 468.

[4] Chem. and Geol. Essays, 189, (1875).

[5] Granulitgebirge, 52--58.

large and excellent work upon "The Granulite District of Saxony," as quoted by Brögger, endeavors to account for the pegmatite veins of that region. He assumes the aqueo-igneous (hydatopyrogene) formation of granite, and pronounces the veins in a sense to be injection veins. "The granitic veins of the granulite district have originated, no doubt, with the aid of more or less water, but this has not been atmospheric water which has percolated downwards through the cracks of the granite, but it is eruptive water, which was given up from the granite to the surrounding rocks, and which, under peculiar conditions obtaining at great depths, was supersaturated with mineral matter." Lehmann assumes for the granitic magma a gelatinous consistency, which was to be accounted for, presumably, by the presence of "viscous silicic acid." "These fluid secretions of granite may be compared to hot jelly." . . . "The capacity of silica to form jellies with much or little water invites strongly to this hypothesis." "Between such a gelatinous magma and a saturated aqueous solution a large number of consecutive intermediate stages can be imagined. In this way, it seems to me, the connection between the pegmatitic veins and the ordinary granites, the remarkable segregations in the shape of pegmatitic veins opening out into druses, and finally the connection of these with vein-fillings which consist only of quartz, tourmaline and potash mica, or of quartz alone, can be explained, etc." Lehmann still farther emphasizes the rôle which water plays in the magma in holding that a high temperature is unnecessary to its formation and evolution. The increasing agency of water brings us next to Reyer,[1] who regarded the pegmatites as excretions of the solidifying magma, representing the last stage of solidification where water was largely active, while Keilhau, Hausmann, and Daubrée regarded the pegmatites as mainly aqueous deposits, but genetically connected with granitic intrusions.

Notwithstanding his belief in the igneous origin of pegmatites in general, Brögger accepts the aqueo-igneous theory for a not insignificant proportion of them. He says[2] the pegmatites, although chiefly magmatically solidified veins, pass into the crack-fillings which succeed them in point of time and which are not in the main, or are not at all, deposited from true magmatic solutions. To this he adds in a foot-

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[1] Theoretische Geologie, 101 (1888).

[2] Canadian Record of Science, **6**, 60.

note, "Many large-grained veins of a pegmatitic structure have been formed principally by pneumatolitic (aqueo-igneous) processes, and not mainly by magmatic solidification," citing as examples the apatite-bearing basic veins and many occurrences of cassiterite, tourmaline, topaz, etc. Also that the muscovite granite pegmatite veins, containing especially beryl, topaz, etc., and having as principal minerals microcline, oligoclase, albite, quartz, muscovite, are, in comparison with the ordinary granite pegmatite veins with which they frequently occur, of somewhat later formation, a slightly different magma, and to a larger extent of pneumatolitic formation.

This review of opinion shows that while several previous writers have recognized the important and necessary agency of water in the formation of pegmatite, varying between heat as the chief agent with water coöperating (igneous processes), and water as the chief agent with heat coöperating (aqueous processes), Lehmann alone has given us a complete statement of the aqueo-igneous theory, or recognized the essential continuity of the igneous and aqueous processes and the consequent complete blending of fusion and solution, and their products — the igneous and aqueous rocks. The present paper may be regarded, therefore, as based upon Lehmann's work — a restatement of his views, with more complete elaboration and illustration in certain directions.

All lavas appear to be more or less hydrated at the time of their extrusion; and, however much opinions may differ concerning the source of the water and its original relations to the magma, it is generally conceded that at the moment of eruption they are very intimately united, and that the former increases the liquidity and the eruptive energy of the latter. Water is very thoroughly diffused through the earth's crust; and it has probably penetrated to so great a depth as to warrant the conclusion that all the so-called igneous rocks now exposed to our observation are in some degree the products of aqueo-igneous fusion. It is unnecessary, however, to insist upon this broad generalization, for, although it may be questioned for some of the plutonic rocks, it is very generally conceded to be true for those with which we now have to do — the acid plutonics or the granites.

The order of crystallization of the component minerals, and the fact that the quartz, which has been in every instance the last mineral to crystallize, is usually crowded with aqueous inclusions, leave no room to doubt that water was present and played an important part in the formation of granite. It is quite unnecessary to raise here the question as to whether or not the granites are metamorphosed sediments; for those who would answer in the negative must, apparently, concede that there is a hydrated zone of the primitive igneous crust beneath the oldest sediments. In fact, the hydration of the original or still unstratified igneous crust to a great depth below the oldest sedimentary rocks appears to the writers a peculiarly safe assumption, for we have to do here with a portion of the primitive crust which formed the immediate floor of the primitive ocean.

Assuming, then, without farther argument, that the granites have been formed in the presence of water, it may be noted that the number, minuteness, and universal presence of the liquid inclusions indicate that, as in modern lavas, the water was very intimately combined with the granite magma. As the magma cools, the various minerals develop and crystallize out in the general order of their basicity, each, in turn, excluding, so far as possible, the still unindividualized magma and water, just as any crystals formed in a solution exclude the solvent. The magma thus becomes steadily more and more acid and hydrated; and when, finally, the free silica alone remains unsolidified, it is probably combined with sufficient water to hold it temporarily in the gelatinous state. As this gelatinous silica slowly and spontaneously dehydrates and crystallizes it necessarily imprisons the main part at least, of the water, which, like a true solvent, is the only part of the magma that remains permanently unsolidified.

Conceive, now, that a large boss or massif of molten granite has invaded the crystalline schists at a great depth and is undergoing extremely slow refrigeration. Crystallization begins on the surface of the mass and gradually extends inward. The rate of cooling diminishes as the crust thickens, but the highly viscous nature of the cooling magma prevents the formation of large crystals. Finally, however, as the outer shell of the boss becomes gradually thicker, the rate of cooling and crystallization are sufficiently reduced to enable the quartz, as it slowly hardens, to exclude a portion of its inclosed water, forcing it inward into the still liquid magma; which is thus rendered more liquid, but not sensibly so at first, for the slowness of the process permits the diffusion of the excluded water through a large volume of unconsolidated magma. The extremely gradual nature of the changes is an essential feature of the explanation. The feldspar and mica probably crystallize in part at least far in advance of the quartz, forming a reticulated or sponge-like zone, through the meshes of which the silica gradually expels a portion of its water. This process is, perhaps, favored by the tendency, through contraction, to reduce the pressure in the interior of the mass. The magma thus becomes, although its temperature is slowly falling, more and more liquid, passing gradually from the condition of aqueo-igneous fusion to that of igneo-aqueous solution; and the greater mobility of the latter state permits the formation of larger crystals. We may thus conceive a perfect blending of the conditions favoring the formation of normal granite in the exterior portion of the mass with those favoring the formation of giant granite or pegmatite in the central portion.

Cooling, crystallization, and dehydration are processes involving contraction, and thus, as in a septarian concretion, there is a manifest tendency to form vacant spaces or cracks in the interior of the boss, in which the highly hydrated and liquid residuum of the magma collects and slowly crystallizes. If these cracks extend through the hard crust of the boss into the surrounding or overlying schists, or if fissures due to extraneous causes penetrate the boss, they will become the seats of sharply outlined and typical veins of pegmatite.

The gradual character of every phase in the refrigeration and solidification of the boss makes it absolutely necessary to suppose that there must be somewhere a perfect gradation from the normal granite to the coarsest pegmatite. As previously stated, this gradation may be observed to some extent in the natural ledges; but we may fairly suppose that, while the cooling of the boss would be partly lateral, it would take place mainly downwards; and since distinct veins of pegmatite represent an actual extravasation of the aqueo-igneous magma, it is apparent that the gradation in question should be sought mainly in depth. It appears to us probable that some of the coarser plutonic rocks, like the syenite of Marblehead, Mass., in a portion of which the crystals of feldspar are from four to six inches in length, should be regarded as intermediate between those of more normal texture and pegmatite.

It is, perhaps, not impossible that a portion of the water required for the more perfect hydration and liquefaction of the residuum of the magma may be derived from extraneous sources. The boss is a great body of magma which has been forced up to, or developed in, a position in the earth's crust far above its normal level. It brings the deep-seated temperature and other conditions up into the region of comparatively active aqueous circulation; and it may be that shrinkage cracks or faults, if not interstitial percolation in accordance with Daubrée's law, would admit meteoric or relatively superficial waters to a participation in the differentiation of the magma.

There appears to be an opportunity presented, also, to apply Soret's principle, upon which Iddings so largely relies, in his valuable essay on the origin of igneous rocks,[1] as a cause of the differentiation of purely igneous magmas. Soret demonstrated that if two parts of a solution of any salt be kept at different temperatures there will be a concentration of the salt in the cooler part of the solution. Iddings holds that in any molten magma certain oxides play the rôle of solvents for the others. But if Soret's principle admits of application to an anhydrous magma, much more should it be applicable to a magma in a state of aqueo-igneous fusion. In the granite boss the cooler part is the exterior, and toward the exterior, therefore, the dissolved bases will be concentrated, leaving in the interior a more highly hydrated portion, which will be in a state of igneo-aqueous fusion, and from which may be developed the coarse crystallization, comb-structure, and pockets of typical pegmatite. This principle probably coöperates with and is, perhaps, intrinsically more important than that of the exclusion of water by crystallization. The main point of this paper is the explanation of the pegmatites through a differentiation of acid magmas in which water plays an important part, the differentiation involving for the magma residuum a transition from aqueo-igneous fusion to igneo-aqueous solution. The possible intervention of extraneous water has been suggested, but this is not deemed essential.

The increase in the degree of hydration of a small part of the magma, through the exclusion of water during solidification by the remainder, is substantially the explanation which Iddings offers for the phenomena presented by spheratites and lithophysæ. A moderate increase in the proportion of water about centers, the proximity of which will be determined by the viscosity of the magma and the rate of cooling and solidification, gives the unsolidified residuum sufficient liquidity to permit the incipient radial crystallization of the spherulite; while a higher degree of local hydration gives rise to the concentric crystalline shells and shrinkage cracks (pockets) with the highly perfect crystallizations of feldspar, quartz, fayalite, etc., characteristic of the typical lithophysæ.

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[1] Bulletin of the Philosophical Society of Washington, **12**, 158.

An analogy may also be traced between this explanation of pegmatite and what appears to us to be the best explanation of the quartz geodes in certain limestone formations. Soluble organic silica originally disseminated through the limestone is dissolved by percolating water and subsequently replaces the calcium carbonate of the limestone about favorable centers. The silica is precipitated and accumulates in a highly hydrated and gelatinous form. Its volume is thus sufficient to fill the globular cavity due to the solution of the limestone; and, theoretically, the accumulation continues until the soluble silica in the tributary portion of the limestone is exhausted. The gelatinous silica then slowly dehydrates and solidifies. This process begins at the surface; a continuous and impervious shell is thus formed; and the remaining silica slowly adds itself to the inner surface of the shell. The viscous nature of the hydrate does not allow the molecules of silica sufficient freedom of movement for the development of a visibly granular or crystalline structure; and the outer layer of the shell is, therefore, cryptocrystalline or chalcedonic. But a process of spontaneous differentiation is in progress. The separation of a portion of the silica renders the solution more mobile, the molecules of silica move more freely, so that cryptocrystallization usually gives way to phenocrystallization, and the inner surface of the geode is studded with large and perfect crystals of quartz. The finely crystalline normal granite forming the main part of a boss corresponds to the chalcedonic shell of a geode, and the central veins and masses of pegmatite to the crystalline lining. The much larger proportion of water in the ball of colloid silica from which a geode is evolved determines a greater preponderance of the coarser crystallization and a relatively larger central cavity or pocket than in the granite boss; while the vastly slower crystallization of the boss prevents, as a rule, even the outer part from being left in the semi-amorphous or felsitic condition, which would be essential to give a perfect correspondence with the chalcedonic outer shell of the geode.

We have observed in New Hampshire, as Williams has in Maryland, and other writers in Europe, a perfect gradation in composition between veins of typical pegmatite and ordinary quartz veins. The quartz veins often intersect the pegmatite and are obviously newer; though it is probable that they are usually substantially contemporaneous with the great masses of quartz which are such a characteristic, as well as the latest, feature of the pegmatite. We hold, with Lehmann, that the most satisfactory explanation of this blending of pegmatite with quartz veins on the one hand, as with normal granite on the other, is to be found in a corresponding blending of aqueo-igneous fusion with igneo-aqueous solution; and this dynamic gradation, it appears to us, can only result from the gradual hydration of the residual magma during the slow centripetal solidification of a body of magma and a consequent elimination of water.

In any case, the solidification and crystallization of a body of magma must be conceived as centripetal; and this consideration makes it impossible for us to agree with Brögger that the water of any considerable volume of magma would pass outward through the constantly thickening shell of granite into the wall-rock. And before the solidification begins the diffusion of the magmatic water through the wall-rock appears equally improbable, since the magma is to be regarded as a chemical union of water and fused rock, a true hydrate, which is dissociated by crystallization, but while actively molten under pressure, absorbing water rather than giving it off. Furthermore, it appears to us probable, or at least possible, that magma injected into the wall-rock may become more liquid, in spite of cooling, through absorption of water; provided the wall-rock has a high temperature or the magma is already sufficiently hydrated to have a low fusing point. Local absorption of water from the wall-rock would best account for the pegmatitic character of the small dikelets or apophyses of granite to be observed on the shores of Marblehead and Swampscott, Mass. The main body of granite is quite free from pegmatitic characters; but the innumerable branches or apophyses of granite ramifying through the bordering diorite are very generally pegmatitic, at least in part, with frequent gradations, the most typical pegmatite passing by insensible steps into the normal granite on the one hand and ordinary vein quartz on the other. The dikelets vary in size from half an inch or less to several feet in width, even the smallest often exhibiting perfectly the gradation just noted; and the pegmatitic character is quite commonly accompanied by a more or less distinct banding or zonal structure — symmetrical bands of feldspar (red orthoclase) on either wall, with quartz and sometimes epidote and allanite in the middle. Long, narrow pockets are a very characteristic feature of these banded veinlets of pegmatite, indicating a high degree of hydration of the magma.

Although the fluidity of the highly hydrated pegmatite magma would make extravasation easy, and thus, perhaps, readily account for the size and number of the pegmatite veins in the surrounding formations, and the fact that they sometimes extend to great distances from the parent plutonic mass ; yet extravasation of a definite pegmatite magma is out of the question in the Marblehead and Swampscott occurrences, and the pegmatite must be due essentially to a differentiation *in situ* of the normal granite magma, the only cause of the differentiation which we are able to recognize being the absorption of water from the wall-rock. While studying the pegmatites of New Hampshire we were strongly impressed, as already noted, by the number, size, and general prominence of the pegmatite veins in the schists, even at considerable distances from the mother rock — the Concord granite, the pegmatite being quite in contrast, in this respect, with the normal granite, which seems to form but few apophyses or dikes in the schists. In fact, we believe it may be truly said that while pegmatite intrusions are especially characteristic of the schists, intrusions of the normal Concord granite occur chiefly in the more massive formations (Winnipesaukee gneiss, porphyritic granite, etc). These considerations have recently suggested to us the following modification or extension of the pegmatite theory :

Pegmatite magma may be formed in two distinct ways : First, by normal magmatic differentiation in a boss or large body of magma, both crystallization and the operation of Soret's principle tending, as already explained, to increase the degree of hydration of the magma residuum about favorable centers. These magma residues may crystallize *in situ* in the midst of the previously solidified normal granite, giving rise to what may be called sedentary pegmatite, which is especially characterized by its gradual passage outward into the normal granite ; or the pegmatite magma may suffer extravasation, finally crystallizing in spaces of discission or dissolution in the parent plutonic, or in the surrounding formations. Second, apophyses of the normal granite magma may invade highly heated, water-bearing formations, such as the schists, and experience the necessary hydration for conversion into pegmatite magma through the absorption of this extraneous water. The high temperature of the wall-rock is essential, as previously noted, to prevent the chilling and crystallization of the magma before the absorption of water can take place.

It cannot be argued that this principle would lead to a peripheral development of pegmatite in the main bodies of granite, for while the volume of water-bearing wall-rock per unit of surface of the body of magma would not be increased, the volume of magma through which the water would be diffused as fast as absorbed would be enormously greater and no exceptional or marked degree of hydration could result. That the wall-rock must have been highly heated, contrary to Lehmann's view, is reasonably certain from the absence in both the granites and pegmatite of the normal gradation in texture due to the chilling action of the walls. On the other hand, this high temperature probably would not tend to expel the water from the inclosing formations, and thus prevent them from contributing water to the invading magmas; for the well-known experiments of Daubrée and Poiseuille indicate that within certain limits, at least, the heat favors rather than hinders the downward progress of the water in the earth's crust; and it appears to us very probable that the absorption of water by deep-seated magmas is another cause operating to the same end. It can hardly be doubted that the temperature was well above the critical point for water, and hence the hydration of the magma really means the absorption of superheated aqueous vapor under enormous pressure. This extension of the pegmatite theory overcomes the obvious difficulty as to the extensive extravasation of pegmatite magma evolved or originating deep down in a great boss of solidified granite; and apophyses of normal granite accompanying pegmatite may reasonably be referred to a somewhat earlier period, when the thermal conditions were still unfavorable to aqueous absorption.

Pegmatite magma may not only be assumed to be more liquid than that of normal granite, but to solidify less promptly, solidification being due only in part to cooling and in part to spontaneous dehydration,— a general principle, the application of which to the pegmatite magma is indicated by the absence of hydrous species among the component minerals. The experiments of Daubrée and others favor the view that the proportion of water essential to the constitution of the pegmatite magma is small; and this is indicated, also, by the infrequent and relatively small pockets; although the enormous pressure prevailing at these great depths may, perhaps, tend to prevent the formation of pockets.

The origin of pegmatites at great depths is suggested by the regional metamorphism of the schists and the consequent general absence of characteristic or significant igneous contact phenomena; and a high temperature may be inferred from the usually jagged out-lines of the veins, indicating a tearing or rending, rather than a breaking, of the rocks, as if they had been softened and toughened by heat. The minute, thread-like veins and apophyses, both of pegmatite and common granite, and the very common lack of gradation along the walls for both rocks, are other facts pointing to the same general conclusions. The pegmatite magma is probably very liquid only in pockets; while for the development of the normal pegmatite a much thinner jelly than the normal granite magma, combined, as in the latter, with extremely slow cooling and dehydration, seems to be required. The order of crystallization shows that pegmatite magma is only a more extreme form of the granite magma. In a true igneous or granite magma, however, the size of the crystals is definitely limited by the viscosity; and beyond a certain point it is practically independent of slowness or rate of cooling. It may be noted, also, that while in pegmatite the tabular and prismatic crystals tend to be perpendicular to the walls, in true magmatic consolidation the orientation of the crystals is essentially indifferent to the walls.

The essential continuity of fusion and aqueous solution is not readily demonstrated by experiment. Under the relatively moderate pressures which have been employed, the addition of heat to a solution, beyond a certain low maximum, vaporizes and expels the solvent; and, in like manner, although the addition of water to a magma promotes liquidity, the amount of water which the magma can retain is insufficient to offset the loss of heat due to the vaporization of water. It is clear, however, that with increased pressure solutions might be hotter and fusions more highly hydrated; and we see no reason to doubt that at moderate depths in the earth heat and water may exist in equal and perfect coöperation. Whether at greater depths igneous fusion prevails must depend, of course, upon the temperature and its relations to the elevation of the fusing point by increase of pressure. The absorption of water under pressure by a liquid magma appears to be a chemical process, a true hydration, the water disappearing as such. If this view be correct, there is certainly some reason to think that we have here a reinforcement of Daubrée's explanation of the downward progress of water in the earth's crust. It is not only urged down by capillary attraction, but also, as previously stated, to make good the loss due to its absorption by deep-seated magmas.

Pressure promotes aqueous absorption and solution, but retards fusion by raising the fusing point. High temperatures, on the other hand, favor fusion, of course, but are antagonistic to aqueous absorption, and hence to solution. If, as we must believe, the pressure increases more rapidly at great depths than the temperature, it may well be, as has been clearly shown by others, that purely igneous fusion nowhere obtains, but the molten magmas at the greatest as well as at moderate depths are in a state of aqueo-igneous fusion. It is a necessary corollary to this view that as refrigeration progresses and water is, in consequence, more abundantly absorbed the degree of liquefaction at a given depth increases until heat and water are in perfect coöperation, and then declines with farther loss of heat, since it is manifestly impossible that sufficient water should be absorbed at any depth to give a general liquid zone by approximately pure solution. It is probable, therefore, that the continuity of fusion and solution is most fully realized during the differential solidification of a body of magma ; and pegmatite is, in a truer sense than any other lithologic type, the connecting link between the igneous and aqueous rocks.

Strictly speaking, nearly all, if not quite all, known rocks are secondary. This is generally conceded for the sedimentary rocks ; but, following Iddings and other recent writers, it must be admitted also for the igneous rocks. A dike is a more or less highly differentiated portion of some deep-seated magma, and it is clearly newer than the walls. An ascensionist, certainly, can say nothing more for a vein, save that while in the formation of the dike heat is the chief agent with water coöperating (aqueo-igneous fusion), in the formation of the vein water is the chief agent with heat coöperating (igneo-aqueous solution). The greater mobility of the solution permits a higher degree of concentration ; but concentration is a universal process and participates in the formation of eruptive masses and sedimentary deposits as well as of veins.

In the opinion of the writers, no sharp line of demarcation can be drawn between dikes and veins, and veins are clearly entitled to some degree of recognition in the lithological classification. In a broad view of the early history of the earth, all the sedimentary and vein rocks are, of course, secondary with reference to the primitive igneous crust, but so are the igneous rocks with which we are now acquainted. Probably none of the igneous rocks which have been studied are truly primitive, and their derivation in some cases from sediments is claimed by many able observers.

Heat and water are the two great agents concerned in the modification and differentiation of the earth's crust; and they are generally, if not everywhere and always, in coöperation, heat prevailing, as a rule, at great depths, and water at the surface. Thus arise the two principal classes of rocks — igneous and aqueous. In either class the rocks may be deep-seated (newer than both walls) or superficial (newer than one wall), in other words, intrusive or contemporaneous. The intrusive igneous masses are known as dikes, etc., and the contemporaneous as lava-flows; while the intrusive aqueous masses are known as veins, etc., and the contemporaneous as sedimentary strata. Between the vein rocks and dike or plutonic rocks we have, at great depths, a perfect transition, in the pegmatites; but between volcanic rocks and sediments transition forms are wanting, because the limited pressure does not permit the perfect coöperation of heat and water.

Since this paper was written, the *16th Annual Report of the United States Geological Survey* has appeared, containing Van Hise's important discussion of the principles of Pre-Cambrian geology. We are pleased to see (p. 687) that he holds very strongly to the essential continuity of fusion and solution at great depths in the earth, and finds in this cöoperation of aqueous and igneous agencies the best explanation of the main part at least of the pegmatites, although holding with Brögger that they are in part of normal igneous origin.

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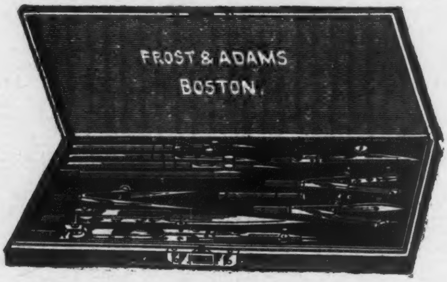
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